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USING TIDAL DATA

by

Francisco Antônio Torres Vidal Abreu

September 1980

Thesis Advisor:	W. C. Thompson
Thesis Co-Advisor:	D. P. Gaver, Jr.

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Determination of Land Elevation Changes Using Tidal Data

by

Francisco António Torres Vidal Abreu
Lieutenant Commander, Portuguese Navy
Portuguese Naval Academy, 1965

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY (HYDROGRAPHY)

from the

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ABSTRACT

The purpose of this thesis is to study the temporal pattern of vertical land movements at selected Pacific Coast tide stations. The relative motion of the land at these stations is indicated by the relationship between monthly mean sea levels measured at pairs of stations. Examination of historical monthly mean sea level data by means of graphical and spectral analysis led to the use of an anomaly filter which adjusts for mean monthly differences. A cumulative analysis procedure of Wyss [1977] was adopted to the study of the relative movement of seven tide stations. Determination of the type of vertical movement between pairs of stations, the date of sudden movement, and the station responsible can be determined from analysis of the cumulative curve of monthly sea level difference. Results of the cumulative analysis show that tide stations, whether separated by short or long distances, experience frequent changes in relative elevation. Whether these are caused by land movements or changes in station datum, or both, is not known.

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I. INTRODUCTION

The determination of relative rates of land elevation change can be made using the resultant information from geodetic work. However, geodetic levelling is repeated very infrequently because it is time consuming and represents a high cost. In coastal areas tidal data, available for many sites, has been used for the same purpose. Its use is not an innovative idea; books and technical papers dealing with this subject have been written by Lisitzin [1974], Roden [1963], Hicks and Shofnos [1965a], Hicks [1972b], and several others. It was, perhaps, the reading of a paper by Balazs and Douglas [unpublished] of the National Geodetic Survey of the National Oceanic and Atmospheric Administration (NOAA) entitled "Geodetic Levelling and the Sea Level Slope Along the California Coast" that constituted the challenge point for the beginning of this thesis. These authors found a clear and large discrepancy between relative movement rates from repeated levellings and tidal observations, but were not able to explain the reasons for that situation.

In this thesis it was decided to use sea level data from several stations on the Pacific Coast of the United States of America aiming at possible establishment of a continuous history of differential vertical land movements among tide stations along this coast. In order to maximize the resolution

of the results it was decided to use mean monthly sea level data, rather than the mean annual data used in some past studies. The data, originated by the National Ocean Survey (NOAA), was provided by the Pacific Environmental Group of the National Marine Fisheries Service (NOAA) located at Monterey, California, and all the computational work was accomplished on the IBM-360 computer at the W. R. Church Center of the Naval Postgraduate School. As some of the received data was not contin is, only periods without missing data were used to avoid the introduction of an uncontrolled source of errors. Table I shows the time series used for each station.

The ocean level is constantly changing and its heights are recorded at long-term tide stations using automatic (analog or digital) methods. The recorded heights are related to the zero of a tide staff which is supposed to be connected by differential levelling to several nearby benchmarks. If the observations are averaged in a special way in order to filter out the short-term water level variations, a value for the mean sea level is obtained. The mean monthly data used here, which is derived from a direct average of all the hourly values during an entire month, can be considered a close approximation to the mean sea level value for the site where it was collected for that averaging interval. But this mean sea level, so important to the hydrographer, geophysicist, and geodesist, is not a constant value

from month to month. Short-term variations of duration less than one month, like oscillations in barometric pressure caused by daily temperature fluctuations, wind effects, seiches, and tsunamis, are some of the causes that give rise to the fluctuations or departures from the mean water level. But exactly because they are transient and of such short-term duration, when averaged over the period of a month they are not significant. Some of the causes of longer term water level variation that account for month-to-month sea level differences are:

(a) The movement of the axis of rotation of the earth (Chandlerian motion) with an approximate period of 14 months.

(b) The nodal cycle of the moon with a period of 18.613 years.

(c) The sun spot cycle with an approximate period of 11 years.

(d) Variations from the average meteorological conditions.

(e) Variation of the average sea water density in the vicinity of the tide station.

(f) Dynamic effect of ocean currents (the last three causes are meteorologically and/or oceanographically induced, producing sea level changes with the following characteristics:

(1) Duration--larger anomalies average about three months but may be as long as 10-34 months [Roden, 1966].

(2) Amplitude--monthly variations from the mean are commonly 100mm but may reach 300mm [Bretschneider, 1980].

(3) Coastwise coherence--very high over distances less than 200 km; significant over distances of the order of 1200 km for tide stations located in the same macro environment [Roden, 1966].

(4) Tide station exposure--within the same macro environment on the open coast and in bays, exposure is relatively unimportant but stations well inside estuaries and fjords where there is large fresh water runoff may be exceptions).

(g) Eustatic changes in elevation of sea level due to the melting of the ice accumulated on the continents.

(h) Any kind of crustal movements, including natural isostatic movements (generally assumed as low and gradual with rates of change varying from zero on stable coasts to approximately 40mm per year [e.g., Hicks and Shofnos, 1965a] in areas of rapid crustal rebound), sudden movements associated with earthquakes and faulting, and the very rapid movements induced by man resulting from oil and groundwater withdrawal, vibrations related with land use, etc.

The presence of long-term vertical movements of both water and land contained in a tidal data time series makes it impossible to determine with high precision the absolute rates of land change. Except for the case of large rates of crustal rebound, we never know with enough confidence if a long term increase of mean sea level was due to land subsidence, to a slow rise of mean sea level, or to both causes.

Lisitzen [1973] and Hicks [1972] tried to estimate absolute rates of land change from single station tide data. The subjective assumptions used by both were not strongly convincing, though with scientific reasons behind them. The former concluded that the eustatic rise of the sea level began in 1891, and the latter simply applied the eustatic sea level rise rate of 1.0mm per year found by Gutenberg [1941] (using sea level data from 69 stations in 22 different regions around the earth). This study deals only with relative rates of change determined from time series data using pairs of tide stations.

Since vertical movement that can occur in the earth's crust is one of the components contained in each tidal time series, it would be a simple matter to quantify this component if all the others could be evaluated and removed from the data. However, this approach is not possible because of lack of data on some components, difficulties in quantifying the effects of other components, and also difficulties in isolating the effect of astronomic tidal components of known period (e.g., the nodal cycle of the moon) from the data.

Using a different approach, it can be said that each monthly time series from a given tide station is composed of random fluctuations (short-term climatological variations are an example), periodical fluctuations (the astronomical components that force the tides and the annual climatological cycle), and what can be considered, at least to a first

approximation, to be linear trends (the eustatic rise of sea level and the movements of the earth's crust). As random and periodic data have no long-term trends in themselves, any trend detected when analysing the data should reflect the latter factors.

Various methods have been used to study sea level changes but only four will be briefly described as a background necessary to introduce and better understand the work done in this thesis:

-Gutenberg [1941] used mean annual sea-level data collected at long-term tide stations around the earth. At that time the unavailability of computers made the use of the least square fitting technique very difficult. The author proposed and used a short-cut system of averaging the first x and the last x years, and dividing the difference between the two means by the number of years between the weighted midpoints of these intervals. His criterion for the selection of x was as follows: If the number of years of data was greater than 25, x should be 10, but if $t < 25$, $x = t/3$. Gutenberg does not speak about errors and the purpose of his paper was to determine the eustatic rate of rise of the sea level.

-Roden [1963], studying sea level variations in Panama, used anomalies of mean monthly sea-level data obtained by taking the difference between the monthly sea level and the long-term mean for the same month. To find the trends, Roden assumes a record $z(t)$ which is the sum of a deterministic

function of time and a stationary random fluctuation,

$$z(t) = a + bt + x(t)$$

where b is an unknown constant representing the long term trend in which we are interested. Here, x(t) is the stationary random fluctuation with zero mean and known autocorrelation or spectrum. Roden uses the solution,

$$\hat{b} = \int_0^T K(T-t)\, z(t)\, dt$$

where T is the record length, and $\hat{b}$ is an estimate of the unknown constant b. The particular shape of the Kernel K(T-t) depends upon the autocorrelation of x(t). The mean square error of the estimate of $\hat{b}$ used was

$$\varepsilon^2 = 12\, \delta^2 / T^3$$

where δ^2 refers to the spike at the origin, assuming white noise.

In a later paper, Roden [1966] uses the expression,

$$b = \frac{6c^2}{c^2T^2 + 6cT + 12} \sum_{t=1}^{T} \left(\frac{2t}{T} - 1 \right) z(t)$$

where c is the constant decay of the autocorrelation of the sea level fluctuations. For the mean square error of the estimate the following expression was used:

$$\varepsilon^2 = \frac{24\, cm_o}{T(c^2T^2 + 6cT + 12)}$$

where m_o denotes the variance of the data.

-Hicks and Shofnos [1965a, 1965b] and Hicks [1972a, 1972b] used yearly mean sea level values weighted by a triangular array (1,2,3,4,3,2,1) and then computed the trends by fitting a least-squares line of regression. The formulas used for the computation of the slope, b, of this line as well as for the standard error of the slope, Sb, are:

$$b = \frac{\Sigma xy - \frac{(\Sigma x)(\Sigma y)}{n}}{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}$$

$$Sb = \frac{Sy.x}{\sqrt{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}}$$

where n represents the number of yearly values. $S^2y.x$ is an estimate of the error variance around the assumed line relating y to x; Sy.x is an estimate of the error standard deviation, and given by:

$$Sy.x = \sqrt{\frac{\Sigma y^2 - \frac{(\Sigma y)^2}{n} - b\left(\Sigma xy - \frac{(\Sigma x)(\Sigma y)}{n}\right)}{n-2}}$$

-Merry [1980] also uses a least-squares fit but applies it to unfiltered daily mean sea levels in a study of secular sea level changes.

One important statement that must be made is that these authors, although using different types of sea level data (daily, monthly, and yearly), different smoothing techniques,

and different methods to determine the trends contained in their data, all assume that both the eustatic rise of the sea level and the movements of the earth's crust can be considered linear to a first approximation. It should also be noted that all dealt with single-station analysis, that is, the data from each tide station was analysed independently of other tide stations to obtain rates of sea level change.

Because of the impossibility of making accurate determination of absolute rates of land change using single station analysis, it was decided to eliminate or greatly minimize the effect of sea level changes in the tide data by comparing the tidal data from several pairs of stations separated by various distances [Table I]. Subtracting from each mean monthly sea level value at station A the corresponding value for the same month and year at station B, we generate a new set of time series data which must contain within itself the relative rate of land elevation change between the two stations, free of any eustatic related trend. Because of the principle on which it is based, we will refer to this procedure as "differential tidal levelling"; the procedure may be thought of as an analog of the method of differential spirit levelling used in geodetic surveying.

In this procedure we assume that the glacial-eustatic, the climatological, and the oceanographic "long term trends" do not significantly differ in themselves over distances on the order of hundreds of kilometers. These are therefore

eliminated in theory by the described differencing computation. The difference between the two series also leaves some random and periodic information that should not introduce any trend. This method, besides allowing the detection of relative rates of land elevation change between any two stations due to tectonic effects, has the advantage of largely removing the short term and seasonal variations, especially at stations separated by short distances. The method also provides a basis for calibration of an entire coast. Nevertheless, it should be used with care particularly when comparing widely separated station pairs, which is a common situation along the west coast of North and South America.

It was with this background that the computational phase began. The next section describes successive efforts to derive rates of land elevation change from sea-level difference data at paired tide stations. Section III treats in detail the procedure introduced by Wyss [1977], and further developed in this study, to accomplish this objective.

II. ALTERNATIVE ANALYSIS OF MEAN MONTHLY SEA LEVEL DATA

The first step taken was to plot the mean monthly sea level data for all of the stations as well as the differences between several pairs of stations. For illustration, three examples are shown on Figures 1, 2, and 3 for the pairs Seattle-Crescent City, San Francisco-San Diego, and Santa Monica-Los Angeles, respectively. Only eight years of data are shown in order to avoid obscuring details. The upper and middle values on each graph represent the data for the first and second station of each pair, the lower values being the resultant difference. Each symbol represents one month (January through December) related with the year indicated, and is obtained from an average computation of hourly values recorded in units of feet. The vertical scale is relative and is the same for all the curves (1 foot/inch).

These three station pairs were selected to illustrate the effect of distance between the stations (note Table I). Each set of station data shows a distinct annual cycle, and it is possible to detect visually a long term trend for a period as short as eight years for some of the stations. The difference data also show this long term trend; however, the annual cycle is not so evident and depends upon the distance between the two stations. The variation of the differences is smallest for the closest station pair due to similarity

of data, which creates a more effective cancellation. The differences appear to be much more random than the original data for each station. Taking differences has the effect of cancelling out systematic variations common to the two series.

The visual evidence of an annual cycle, despite being disguised in the difference data, oriented this work toward the need for a spectral analysis of station data in order to determine if other frequencies with significant energy are present. The occurrence of annual and other cycles would justify a filtering operation before treating the data for trends. The short length of some of the time series was a clear temptation to perform the analysis with a small number of degrees of freedom (with a correspondent lack of confidence in the results), but stations like Seattle and San Francisco with at least 912 data points (76 years) allowed the use of 16 degrees of freedom. The spectral analysis was performed on several stations for 2, 8, and 16 degrees of freedom with the subroutine PREPFA, shown in Appendix A-1, using the principle of the Fast Fourier Transform (FFT). Other subroutines called by PREPFA can be found in Appendix A-5, except PLOTG and RHARM which are library subroutines of the W. R. Church Computer Center.

Figures 4, 5, and 6 show the power density function of the spectra for Seattle data for 2, 8, and 16 degrees of freedom, respectively (note different scales). Figures 7, 8, and 9 are the corresponding graphs for San Francisco.

For both stations the maximum detectable frequency is 0.5 cycles per month. This frequency, $Fn = \frac{1}{2\Delta t}$, is determined by the time interval Δt between each data point, where Fn is the Nyquist frequency and $\Delta t = 1$ month. In all six figures noticeable sharp concentrations of energy (peaks) are seen to occur only in the low frequency part, with almost nothing at higher frequencies. The typical decrease of noise with increasing frequency may be seen best in Figure 7. Identifiable by their high concentration of energy, only the frequencies of 0.083 and 0.167 cycles per month could be found. These correspond to the annual and semi-annual cycles. These prominant peaks, although coincident with the tidal constituents Sa and Ssa, are essentially of meteorological and oceanographic origin. Thus, with so high a concentration of energy at these specific frequencies with a periodic origin (but not absolutely repetitive year after year), it was decided to eliminate this interference from the station data before computing long-term sea level trends.

In order to remove the two prominent cycles appearing in the spectra, it was decided to experiment with two different types of filters. A principle to be adhered to was that the annual and semi-annual cycle should be removed without significantly modifying the proportionality of the energy existing at the other frequencies. This requirement of maintaining the energy proportionality was adopted to guarantee that only the periodic components in the station data, which do not

contribute to the long-term trend, are removed by the filtering process.

The first filter used is a simple 12-month running mean, 12 months being the length of the averaging window needed to remove the effects of both the annual and semi-annual cycles. The operation of this filter is very easy. The first data point is obtained by averaging the first 12 data points from the raw data, the second is obtained by averaging the next 12 data points (2 through 13), and so on. It is obvious that with this method, so often used in practice, we are introducing a "tail" effect. During the entire averaging process the first and the last (nth) data points were just called once, the second and the (n-1)th twice, ..., while all the data points between and including the 12th and the (n-11)th were used twelve times. A subtle consequence is that the filtered data series is 11 months (11 data points) shorter than the raw data series, so that the sea level trends computed from the raw and filtered data may be expected to differ slightly. Nevertheless, it is a very effective filter for special applications.

The second filter used removes the long-term mean monthly sea levels from the raw monthly data to produce a time series of monthly sea level anomalies. This is accomplished by first averaging the sea level values for each month (i.e., first for January, then February, and so on) and then subtracting these 12 means from the respective monthly values

in the raw record. The result is a record of monthly sea level anomalies relative to the long-term mean monthly sea levels.

For all three sets of monthly station data, i.e., the unfiltered sea level values termed the raw data, the 12-month running mean data, and the anomaly data, the trend, the scatter of the monthly values, and the standard error of the slope were obtained using the conventional least-square formulas referred to in the introduction. Some comments will be made later about the errors introduced with the use of these formulas when the data are correlated. The computer program used to perform these calculations was subroutine LEASTS, found in Appendix A-2. Appendix A-3 gives the subroutines RMEAN1 and ANOMAL written to perform the two types of filtering just described.

An example, using four stations, of the effects of applying these filters to the raw data is illustrated in Table II. The table shows that for a given station, the sea level trend computed by the three methods agrees quite closely. The values that describe the scatter of the data and the standard error of the trend are what would be expected from the three methods, i.e., smaller values for the scatter of the 12-month running means than for the raw data or anomalies. The reader should be cautioned not to compare the trends between stations because they are obtained from different series of years.

With regard to the variability of the filtered data compared to the variability of the raw data, a better feeling can be obtained through Figures 10, 11, 12, and 13. Each graph shows from top to bottom the raw data, the 12-month running means, and the anomalies for the first eight years of tidal series at stations Seattle, San Francisco, Santa Monica, and Los Angeles, respectively. These four figures, in conjunction with Table II, show that the trends and the variabilities of the anomalies are much closer to those of the raw data.

It was stated above that it was desired that the filters used should remove only the annual and semi-annual components and that the spectra of the filtered data should maintain the proportionality of the energy distribution with frequency observed in the spectrum of the raw data. The question of whether the two filters used satisfy these conditions will now be addressed. The transfer function for each filter is different, and so the results of the spectral analysis may be expected to differ somewhat. This study was done using four stations with the indicated 2, 8, and 16 degrees of freedom, but the results for only two stations for 2 degrees of freedom are presented. Figures 14 and 15 refer to Seattle and show the spectra resulting from the application of the 12-month running mean and the anomaly filters, respectively; these should be compared to the spectrum for the raw data shown in Figure 4. Similar spectra for San Francisco are

shown in Figures 16 and 17 and should be compared to Figure 7. The differences can be seen more quantitatively in Table III, which is discussed below.

From visual inspection of these figures it can be seen that both filters very effectively eliminate the annual and semi-annual components, but while the running window filter removes practically all the energy contained in frequencies greater than that of the annual cycle, the anomaly filter eliminates only the undesirable peaks of one cycle/year, two cycles/year, and multiples of these frequencies, leaving the energy at the other frequencies with the same approximate proportionality. To illustrate the effects of the filters quantitatively, Table III shows energy density ratios obtained from comparison of these spectra for Seattle (using 16 degrees of freedom). By removing the values closest to the periods which we intend to eliminate (12 and 6 months), the quotient (3)/(5) is seen to vary between the values of 1.272 and 0.888, while the quotient (3)/(4) varies between 1.330 and infinity. The same conclusion can be reached also by visual comparison of the plots.

After this examination the conclusion that all further work should be prosecuted using the anomalies was reached. Nevertheless, in order to further compare the filtering procedures, the raw data and both sets of filtered data were used in the following investigations. The sea level trends for three tide stations computed for different time intervals

are shown in Table IV. The table shows that the trends are time dependent. These results were not unexpected because other authors [Gutenberg, 1941 and Roden, 1966] already referred to the problem of the "instability" of the long term trends.

Although the trends of the sea level at one individual station are clearly shown not to be constant, there is reason to believe that the trend of the differences in monthly sea level between a pair of stations, particularly closely spaced stations, might be much more nearly constant. In order to inquire into this question the following experiments were performed. Programs were run in order to find and plot the running trends of the differences, where the trend was computed for a selected time interval or window. Thus, for a given time series of monthly sea level differences between two stations, the trend for the first x years is computed, where x is the window length, then the operation is repeated by stepping the window one month at a time and computing a new trend. The result is a graphical computation of a time series for an x-year trend for a given station pair. The selection of the window length was not arbitrary. Knowing the existence of long period tidal components expected to be contained in the tidal series, including the regression of the moon's node (18.613 years), the revolution of the lunar perigee (8.847 years), and the revolution of the solar perigee (20.940 years), the closest numbers of integer months to these

values were chosen. The results, which are not presented, did not show a constant value for the trend of differences within some reasonable standard error. It was only obvious that by increasing the length of the window the variability of the resultant trends was decreasing, which was expected.

In order to go further in this analysis, plots and computations were made for several pairs of stations using windows covering 10, 20, 30, and 40 years of data, when possible. Also, raw and filtered data were used in all experiments. For illustration, Figures 18, 19, and 20 show for the station pair Santa Monica-Los Angeles (SM-LA) the trends for the monthly difference data; also shown are the trends for each station. The length of the window used is 10 years. These three figures refer to the raw data, 12-month running means, and anomalies, respectively. The pattern presented using these types of data is almost the same. The yearly cycles are evident in the raw data computations (Figure 18), and the degrees of smoothing obtained with the filters can be observed in Figures 19 and 20. An important observation relates to the variability of trends obtained for a close pair of stations. For the station pair of SM-LA the trends of the differences range between -2.5 and +7.0 mm/year for the period considered. This suggests that for this specific time-window (10 years), time periods can be found during which Santa Monica rose relative to Los Angeles (or Los Angeles subsided relative to Santa Monica) while other

periods reflect the opposite. On the time ordinate in these figures "mean year" means the central year of the window used for the calculation of the trends. To show how the variability of the trends for each station and for the differences are smoothed with an increase of the window length, Figures 21, 22, and 23 show the trends of the monthly anomaly data using 20, 30, and 40-year trend windows. All refer to the pair Seattle-San Francisco (SE-SF). The difference curve is the lowest one on all the graphs.

These demonstrations show that the sea level trend is determined, in part, by both the width and the mean position in time of the window used; accordingly, it was determined that the aim of this work should be modified. Instead of trying to refine or otherwise improve on the values already published by several authors using single station tide measurements to estimate rates of land change, the study was reoriented in order to find the evolution with time of the relative movement between two stations. This will be the topic of the next chapter.

III. THE CUMULATIVE PROCEDURE

Wyss [1977], in a study of land elevation changes associated with earthquake occurrence, introduced a method of cumulative analysis using monthly sea level differences between two very close tide stations. In order to apply this technique, it is desirable to adjust the monthly sea levels at one station relative to the other so that their means are equal. Thus, if for stations A and B, all the data values of B were modified in order to make the average of B equal to the average of A, the differences between A and B would have values with a random variation around zero. The difference values, (A-B), are then cumulated in a time series beginning with the earliest monthly difference value. The cumulative curve that results will be a random walk around the value zero if the sea level history at the two stations is identical. There will be swings up and down, but eventually a return to zero will occur. If the elevation of one station relative to the other is different, this random plot will soon show an evident and pronounced trend. In this case, if the monthly differences are cumulated over many years, very large cumulated differences amounting to many feet may result.

Now, if the relative elevation changes suddenly instead of cumulating small positive or negative values around zero, values containing a constant increment (positive or negative)

are now added introducing a trend on the random data, and an inflection point will appear in the cumulative curve. The difference between slopes on each side of the discontinuity allows determination of the amount of relative elevation change. The inflection point, itself, allows the identification of the date for relative elevation change. In the case of a sudden elevation change or jump revealed by a cumulative curve, the station which is responsible cannot be identified. However, the latter can be determined when more than one station pair is used because a change in the slope of the cumulative curves must occur at the same time in all pairs of stations containing the common station.

Before examining the results of the cumulative analysis, further explanation must be given about the kind of curves that can be expected when using the cumulative procedure. As was said before, there is strong reason to reject the assumption of long-term linear sea level changes, but there is no reason to avoid the assumption of linear relative elevation changes occurring over short periods of time. If we make this assumption, only two possibilities can occur. Either the two stations are stable relative to one another and the trend of the monthly sea level differences between them is zero, or there is elevation convergence (a negative trend) or divergence (a positive trend) between both stations. In the first case, a straight line will be shown in the cumulative curve, with a positive or negative slope, depending on

whether the elevation of one station is higher or lower than the other; the linear segment will be horizontal if the means of the monthly sea levels are equal at the two stations for the time period represented. In the second case, if the monthly differences converge or diverge, the amount to be summed each time is different from the preceding value and follows a linear law of variation. The cumulative curve will then show a parabola with a negative or positive slope, respectively. Subroutine CUMMUL,(Appendix A-4), was written to perform this type of analysis.

To illustrate the above description of straight line segments with different slopes, as well as branches of parabolas with positive and negative slopes, some of the cumulative graphs produced are presented. Figures 24, 25, and 26 show the cumulative differences for the pair Seattle-Los Angeles using raw data, anomalies, and 12 months running means (three sets of curves were produced for all pairs of stations because the different degrees of smoothing on each curve were helpful for identifying the inflection points). One interpretation of the cumulative curve in these figures is that they consist of three legs or segments, the first one between 1924 and 1947, and the other two between 1948-1965 and 1966-1974. This pattern in which the cumulative values become more negative and suddenly change toward more positive was not expected. These graphs show that the averaging procedure used to achieve an initial matching of the data for both stations was not the

most suitable because it caused a change in slope from negative to positive, thereby suggesting a change in sign of the movement between the two stations. From the three figures we can see that the Seattle data was negative relative to the Los Angeles data during the first interval and became positive during the second and third legs. The absolute values of the slopes of the first and second legs strongly suggest that some event occurred about the end of the year 1947. Nevertheless, it must be noted that in 1947 a change in the sign of the slope also occurred. A change in the sign of the slope of a cumulative curve means that one data set crosses the other, so that the sign of the differences reverses. If the cumulative curve is made by linear legs, then a symmetrical picture results in which the slope on either side of the crossing point has the same magnitude but is opposite on sign. In Figure 24, the character of the discontinuity shows that not only did a "jump" occur between the two stations but the "jump" caused a reversal in the sign of the differences. In order to avoid misinterpretation of the cumulative graphs, the decision was made to recumulate the monthly difference values after first equating the initial data point of each station. The graphs presented in Figures 27, 28, and 29 show these results for the same pair of stations, using raw, anomaly, and 12-month running mean data, respectively. Their appearance is seen to be markedly different from Figures 24-26. This group of six plots was helpful

in two ways; first, inflection points are easily identified, and second, the apparent differential station movements can be isolated from background noise. This procedure of producing a set of six plots for each pair of stations was the routine used for all possible pairs among the seven stations dealt with.

The cumulative curves in Figures 28 and 29 never cross the zero line. Their relatively smooth appearance could lead to an alternative interpretation that instead of three straight line legs, the curves could be viewed as a long branch of a parabola. This interpretation could justify the computation of a single difference trend for the entire data series. From simple observation, there is no doubt that the long term trend between the two stations must be positive; the value of 2.13 mm/yr $\pm$0.28 mm/yr is obtained for the entire raw data series (1924-1974).

In order to test the hypothesis of these cumulative curves being composed of three straight line segments versus a branch of a parabola, two methods were used.

The first method, assuming the curves to be composed of three linear segments, was to calculate the differential sea level trends from the monthly difference values for each leg. The results obtained for SE-LA are given in the upper part of Table V. The three values for the trends are very close to zero, indicating similar movement at both stations during each period, but also that "jumps" occurred between each leg.

The measure of a "jump" can be obtained (as already explained) by computing the difference between the slopes of the adjacent legs on the cumulative curve.

The second test was to perform a least-squares best fit to obtain the hypothetical parabola represented by the cumulative data of Figures 24 through 29, and then to compute and plot the residuals obtained by taking the differences between the cumulative curve and the best fit parabola. For this purpose subroutine LSQPL2, a library subroutine of the Computer Center of the Naval Postgraduate School, was used. The residuals between the cumulative curve of Figure 27 and the best fit parabola are shown on Figure 30. It is clear that the variation of the residuals is not random, and some structure can be observed such as would be expected from fitting a parabola to straight line segments. The next step was to fit each one of the three segments of the cumulative distribution with first degree curves (straight lines) and again compute the residuals. If the hypothesis of three linear legs is reasonable, the variance of the residuals should show a significant decrease and should display a more random distribution around zero. Figures 31, 32, and 33 illustrate these residuals for the first, second, and third legs, respectively. The randomness around zero is evident, at least for the periods shown in Figures 32 and 33, and a decrease of the extreme values can also be observed. Thus, if the cumulative curve for SE-LA indicates three intervals of constant elevation

difference between stations, the jumps indicated about 1947 and 1965 amount to 4.6cm and 4.4cm, respectively. Another conclusion can also be extracted from this analysis of the residuals. Both Figures 31 and 30 clearly show a unique structure in the data between the end of 1927 and 1934, suggesting that something of geological significance may have happened between these dates.

Similar tests were performed for several pairs of stations where the cumulative curve suggested the possibility of a single long term difference trend. Figure 34 is an example. This curve was initially chopped into three pieces. The first branch of parabola included the period from 1950 to 1959, the second from 1960 to 1964, and the last from 1964 to the end of the series. The values for the trends of the partial series as well as the entire series, computed from the monthly differences, are shown in the lower part of Table V. The test of the residuals was also applied, this time with three second-degree curves for the best fit of each branch. The results were similar to those for the SE-LA station pair. Again, the analysis of all pairs containing SF and CC not only allowed the identification of the inflection points, but also allowed identification of the station whose movement was responsible for it.

An example of station identification can be observed in Figure 35, where a change of movement occurred near the end of 1960. This figure refers to the pair SF-LA where the

movement which occurred in 1947 can also be seen. By comparing the plots for SE-LA (Figures 24-29) with the plot from SF-LA (Figure 35), it is seen that an inflection point occurs on both plots for 1947. Therefore, Los Angeles must be the station responsible for this inflection. Near the end of 1960 a similar movement appeared on plots SF-CC and SF-LA. Using the same logic, SF is the responsible station. Figures 36 and 37 show plots similar to Figures 1, 2, and 3, but include the periods containing the inflections of 1947 and 1960 for the pair SF-LA.

Cumulative analyses were made of the 21 possible station pairs for the seven stations analysed. Two plots are presented in Figures 38 and 39 which illustrate some of the typical situations that were found. By disregarding small features, Figure 38 shows three distinct periods. The first one ends in 1959 and has a positive trend. The second one extends from 1959 to 1963 with a negative trend, and a third leg (almost linear) has a trend close to zero. Figure 39 shows six distinct straight line segments with different slopes and a small part of a parabola (between the end of 1951 and the end of 1952). All of the cumulative distributions appear to show only segments of straight lines and branches of parabolas. Therefore, it can be assumed that the difference data represents dominantly linear sea level trends.

At this point it is of interest to present the results of cumulative analysis applied to the seven tide stations studied. The method chosen to do this is to reference the relative vertical motions to a single station on the coast. San Francisco was chosen as the reference station because of its long time series without missing data (1899-1978) and also because only two vertical movements were ascribed to it during this long period. Table VI shows, for the time intervals listed, the sea level trends and errors in the trends for SE, CC, AV, and LA relative to SF. Assuming that San Francisco experienced discontinuous movements only in 1931 and 1960, all the other movements indicated by the boundaries between the time intervals shown are attributed to the other four stations. Although the sea level trend history for each station relative to the reference station could theoretically be determined directly from linear and parabolic segments fitted to the cumulative plots produced, time did not permit this. Trends shown in the table were instead computed by fitting linear curves to the station difference data for each of the many intervals between the identified inflection points. Identification of the inflection points was found in some cases to be quite subjective. It should also be noted that the cumulative curves of nearly all station pairs that include SF appear to consist of parabolic segments.

Additional comments regarding the data in Table VI are necessary. The first one is that very short-term trends,

which cover a length of time like one year or two, must be looked upon with suspicion because they are dominated by the assymetry of the annual cycle still present in the difference data. Second, the stations of Santa Monica and San Diego were not included in the table because all cumulative plots including these two stations show a complicated pattern with continuous and aperiodic waves. The other cumulative graphs show generally well defined patterns leading to easy identification of movements. Some dates of relative sea level rate change at these stations are suspected, e.g., Santa Monica in 1941, 1945, 1955, and 1956 and San Diego in 1942, 1950, and 1959, but it is impossible to define these discontinuities with the same confidence as for the other five stations. Also, it is evident from Table VI that as the length of each period under analysis decreases, the standard error of the slope increases. This is a price that must be paid when using cumulative analysis. The detection of apparent inflection points results in chopping the entire time series into shorter segments, with the corresponding reduction in confidence in the trends obtained.

Some comments must be made about the computations of the trends as well as about the corresponding errors. The standard least-squares formulas used by other investigators in this field and also used in this thesis are not the most appropriate if the data to which a curve is to be fitted is not independently random. High correlation between the

monthly sea level values can be observed in the correlograms in Figures 40, 41, 42, and 43, prepared for Seattle, San Francisco, Santa Monica, and Los Angeles, respectively. Nevertheless, if the length of the series is large and it is assumed that for each time segment the trend of the data is smooth, a reasonable approximation is obtained for the value of the slope. But a poor approximation of the standard error of the slope results if the time series is short and the data fluctuations are not independently random. In order to obtain a representative standard error a corrective factor must be applied to the conventionally calculated standard error. This factor [Bloomfield, 1980] is:

$$\sqrt{1 + 2\sum_{\tau=1}^{\infty}\rho_\tau}$$

where τ is the time lag in months and ρ_τ is the autocorrelation function at lag τ. This factor is positive, greater than one, and multiplicative; accordingly, it introduces an amplification of the value of the standard error of the slope. If, for simplification, a geometric decay of the correlogram is assumed (and that is not always the case) this formula can be simplified to

$$\sqrt{\frac{1 + \rho_1}{1 - \rho_1}}$$

where ρ_1 is the value of the autocorrelation function for a time lag equal to one.

Figures 44 and 45 show the correlograms for the differences (using anomalies) between the pairs SE-SF and SM-LA. From these two examples it can be seen that the variability of the trend found with the ordinary least-squares formula should be increased for the first case by a factor of 1.3, using $\rho_1 = 0.26$, and for the second case this factor is 2.17, using $\rho_1 = 0.65$. Thus, the calculation of the corrective factor is different for each pair of stations and must be computed separately for each case. The values obtained for SE-SF, CC-SF, SF-AV and SF-LA, are 1.83, 1.69, 1.91, and 1.91, respectively. As the confidence limits for some of the trends are relatively large, the associated trends can be largely disregarded. Thus, care must be taken with the contained information, even knowing that it represents the most probable values.

As an example of the interpretation of Table VI, the positive relative trend shown for SE (2.34 mm/yr) for the period 1899-1910 means that sea level was rising at Seattle relative to San Francisco or that the Seattle tide station was subsiding relative to San Francisco during that period of time.

The question should be raised as to the cause of the relative vertical motions between tide stations determined from the application of the cumulative analysis. There are two plausible causes for the sea level differences:

(1) Occasionally or steadily occurring real land elevation changes. It should be pointed out here that the occurrence of sudden movements as shown on the cumulative plots agrees with results found from on-going studies using Very Long Baseline Interferometry to the effect that crustal plate motions in California may be characteristically jerky at regional scales of hundreds of kilometers and not continuously slow and smooth [Whitcomb, 1980]. Differential tidal levelling in the Salton Sea reported by Wilson [1980] also indicates jerky crustal movements.

(2) Occasionally occurring changes in the station datum. These may be due to tide staff displacement, replacement of the staff or gage, moving the gage, displacement of the instrument datum, construction work at the pier, etc. These kinds of changes are likely to be very small, although they appear to be detectable by the cumulative analysis technique.

Insufficient time and information precluded this study from determining which of the above phenomena was responsible for the movement for each disturbance data at each station.

IV. SUMMARY AND CONCLUSIONS

This thesis investigated the problem of determining the rate of land elevation change from monthly mean sea level data. The techniques used by different authors are surveyed as well as the different types of data and methods used for the calculation of trends. The assumption of linearity of the sea level trend used by previous authors in estimating absolute rates of land elevation change is also discussed. In addition, causes of water level variation contained in monthly sea level time series are enumerated. Because of the impossibility of separating the many components, it is concluded that absolute values for the rates of either sea level change or land elevation change cannot be found. Accordingly, the use of a differential tide levelling process was proposed in which the elevation of one tide station relative to another is determined.

In the experimental phase, mean monthly sea levels at seven tide stations on the Pacific Coast of the United States were chosen for study. Spectral analysis was first performed, and this showed peaked concentrations of energy around the annual and semi-annual cycles for all stations. Except for these frequencies, the spectrum up to the frequency of 0.5 cycles per month contained only noise, showing a typical decay with increasing frequency. These concentrations of energy,

essentially of meteorological and oceanographic origin, were then filtered out of the monthly station data using two filtering processes, a 12-month running mean filter and an anomaly filter. Descriptions of these filters are given in the text. The effect of each filter on removing the annual and semi-annual cycles without otherwise altering the properties of the monthly sea level data was then tested by comparing the power density spectrum of the filtered time series with that of the raw monthly data. The results obtained favor the use of the anomaly filter for future work because it eliminates the concentration of undesirable energy in all other frequencies found in the unfiltered data.

Several experiments were performed in computing sea level trends from sea level difference data, both filtered and unfiltered, using running intervals or windows with arbitrary and non-arbitrary time lengths. It was found that the sea level trend determined for a given station is dependent on the window length used, the chronological location of the window in the time series, and whether the monthly sea level values used are unfiltered (raw) data, 12-month running mean data, or anomaly data. Because of these totally time dependent results obtained for sea level trends, attention was redirected to the use of a new technique introduced by Wyss [1977] involving cumulative analysis of time series data. The method, termed here the cumulative analysis procedure, which is further developed in this thesis, involves cumulation

of the monthly values from beginning to end of a tide series. For this purpose, the monthly sea levels for the seven tide stations studied (Seattle to San Diego) were combined to yield 21 station pairs. The cumulative plot for a typical station pair appears to be composed of straight line segments and branches of parabolas. The linear segments represent time intervals during which the elevation of the two stations remains constant, while parabolic segments indicate a linear rate of change in elevation occurring between the stations. The segments vary in length up to 17 years. The fact that each cumulative curve consists of several segments indicates that differential vertical movements between tide stations, whether separated by short or long distances, occur frequently.

Also noted in some of the cumulative curves are inflection points. These indicate a sudden vertical displacement of one tide station relative to another. The cumulative curve containing an inflection does not reveal at which station the movement occurred, but the responsible station can be identified from examination of two or more cumulative curves containing the station.

The process of chopping the cumulative curve into segments (and of determining whether each segment is linear or curvilinear) was found in some cases to be quite subjective. Accordingly, tests were devised, and applied to selected cumulative curves, to determine whether each segment identified is best represented by a linear or a parabolic fit.

The first test compares the residuals obtained between a best fit parabola and the cumulative curve with residuals obtained between a best fit line segment and the same cumulative curve. The other test compares the sea level difference trend for each well defined segment of the cumulative curve with the long term difference trend obtained for the entire time series.

The cumulative procedure, although limited by subjective interpretation of the cumulative curve, is sensitive to very small sudden or continuous changes in the elevation of one tide station relative to another. In addition, in contrast to conventional geodetic methods, application of the procedure produces a continuous history, month by month, of differential elevation changes between two stations (over the period of common tide measurements). It is recommended that the cumulative procedure be used in future analyses of tidal data time series, although further investigation should be done to refine the analysis techniques. It should also be determined whether, for the tide stations studied, the changes in elevation of one station relative to another are caused by real land elevation changes or by changes in station datum, or both.

TABLE I

TIME SERIES USED FOR EACH TIDAL STATION

Station	Symbol	Number of Years	Time Series	Approximate Distance Between Stations
Seattle	SE	76	1899-1974	
				685 Km
Crescent City	CC	25	1950-1974	
				481 Km
San Francisco	SF	80	1899-1978	
				333 Km
Avila	AV	14	1946-1959	
				244 Km
Santa Monica	SM	33	1933-1965	
				38 Km
Los Angeles	LA	55	1924-1978	
				153 Km
San Diego	SD	31	1931-1961	

Note: The data format for all the stations was mean monthly sea level values in feet on computer cards.

TABLE II

DIFFERENCES OBTAINED FOR LONG TERM TRENDS
WHEN USING RAW AND FILTERED DATA

		Seattle (1899-1974)	San Francisco (1899-1974)	Santa Monica (1933-1965)	Los Angeles (1924-1978)
Record length:		76 yrs	76 yrs	33 yrs	55 yrs
Raw data:	b	1.922609	1.911846	2.814878	0.590955
	Sy.x	84.77	59.263117	63.338516	60.829502
	Sb	0.127954	0.089446	0.334117	0.149132
12 Month	b	1.912255	1.886021	2.541461	0.510632
running	Sy.x	30.506815	29.897564	29.283841	26.579253
means	Sb	0.046890	0.045953	0.161142	0.066826
Anomalies:	b	1.927965	1.905879	2.718758	0.555566
	Sy.x	62.328436	50.409106	42.951712	39.328127
	Sb	0.094073	0.076083	0.226574	0.096418

where: b is the slope of the long term trend in mm/yr; positive values indicate a rising sea level trend for the entire record.

Sy.x is an estimate of the error standard deviation in mm.

Sb is the standard error of the slope in mm/yr about the long term trend. It was calculated as if the fluctuation of the monthly values are independent. These estimates of the standard error are almost certainly too small.

TABLE III

COMPARISON OF SPECTRA FOR SEATTLE DERIVED FROM THE RAW DATA, 12-MONTH RUNNING MEANS, AND ANOMALIES (16 DEGREES OF FREEDOM)

		Energy Density (feet sq. x month)			Quotients	
(1) Period (months)	(2) Frequency (cyc./mo.)	(3) Raw Data	(4) 12 mo. r.m.	(5) Anomalies	(3)/(4)	(3)/(5)
64.000	0.016	0.173	0.130	0.177	1.330	0.977
21.333	0.047	0.091	0.024	0.079	3.791	1.151
12.800	0.078	1.324	0.002	0.112	662.000	11.820
9.143	0.109	0.214	0.004	0.098	53.500	2.183
7.111	0.141	0.103	0.001	0.067	103.000	1.537
5.818	0.172	0.188	0.000	0.070	∞	2.685
4.293	0.203	0.084	0.002	0.066	42.000	1.272
4.267	0.234	0.072	0.001	0.080	72.000	0.900
3.765	0.266	0.043	0.000	0.034	∞	1.264
3.368	0.297	0.075	0.001	0.069	75.000	1.086
3.048	0.328	0.059	0.000	0.053	∞	1.113
2.783	0.359	0.052	0.000	0.053	∞	0.981
2.560	0.391	0.030	0.000	0.027	∞	1.111
2.370	0.422	0.048	0.000	0.054	∞	0.888
2.207	0.453	0.062	0.000	0.060	∞	1.033
2.065	0.484	0.033	0.000	0.030	∞	1.100
2.000	0.500	0.025	0.000	0.024	∞	1.041

Note: Only alternative values of frequencies are shown; ($\Delta f = 0.0155$ cycles/month).

TABLE IV

SEA LEVEL TRENDS OBTAINED FOR THREE STATIONS
USING DIFFERENT LENGTHS OF TIME SERIES

Station	Time Period	Trend (mm/yr) Raw data	12 mo.r.m.	Anomalies
Seattle	1899-1974 (76 yr)	1.92261	1.91226	1.92796
Seattle	1899-1968 (70 yr)	1.80475	1.74807	1.81080
Seattle	1924-1973 (50 yr)	2.73895	2.71548	2.74963
Seattle	1924-1947 (24 yr)	2.44849	2.79119	2.50428
Seattle	1948-1965 (18 yr)	1.83066	1.77530	1.89668
San Francisco	1899-1978 (80 yr)	1.83336	1.81182	1.82822
San Francisco	1924-1973 (50 yr)	2.36677	2.34899	2.35055
San Francisco	1899-1968 (70 yr)	1.87412	1.84081	1.86713
San Francisco	1924-1978 (55 yr)	2.11264	2.06595	2.09943
San Francisco	1899-1974 (76 yr)	1.91185	1.88602	1.90588
Los Angeles	1933-1962 (30 yr)	1.06396	0.85891	0.94343
Los Angeles	1924-1973 (50 yr)	0.63811	0.61212	0.59517
Los Angeles	1924-1947 (24 yr)	2.41874	2.39378	2.23160
Los Angeles	1948-1965 (18 yr)	1.47915	0.90488	1.14511
Los Angeles	1924-1978 (55 yr)	0.59096	0.51063	0.55557

TABLE V

TRENDS OF THE DIFFERENCE DATA FOR PAIRS OF TIDE STATIONS FOR SPECIFIC TIME SERIES

Station	Time Period	Trend (millimeters per year) Partial Series	Trend (millimeters per year) Full Series
SE-LA	1924-1947 (24 yr)	0.0297	2.1375
SE-LA	1948-1965 (18 yr)	0.3513	(1924-1974)
SE-LA	1966-1974 (9 yr)	-0.0953	
SF-CC	1950-1959 (10 yr)	7.1997	3.2682
SF-CC	1960-1964 (5 yr)	12.7439	(1950-1974)
SF-CC	1965-1974 (10 yr)	3.4339	

TABLE VI

TRENDS OF ELEVATION CHANGE RELATIVE TO SAN FRANCISCO

Stations	Time Period	Trend (mm/yr)	Standard Error of the Slope (mm/yr)
SE-SF	1899-1910	2.34497	1.993378
	1911-1927	1.01102	1.089108
	1928-1931	-3.92303	8.252379
	1932-1934	3.86056	19.600630
	1935-1945	0.27098	2.021985
	1946-1952	-7.65468	4.130359
	1953-1960	-4.05034	3.501000
	1961-1965	-12.63590	6.847633
	1966-1974	-0.87969	2.938892
full series	1899-1974	-0.01075	0.119488
CC-SF	1950-1954	1.01228	4.633611
	1955-1959	-10.63333	5.191369
	1960-1960	-49.87460	46.494390
	1961-1963	-15.23740	9.759881
	1964-1974	-2.48234	1.627356
full series	1950-1974	-3.26817	0.455462
SF-AV	1946-1947	25.50820	12.868782
	1948-1952	-7.61081	2.991260
	1953-1959	-0.16552	2.754739
full series	1946-1959	-0.14199	0.862576
SF-LA	1924-1931	-2.19510	1.909139
	1932-1947	1.75783	0.758469
	1948-1960	1.21958	1.011479
	1961-1970	3.62779	1.557846
	1971-1978	-3.91764	2.136735
full series	1924-1978	1.52172	0.121347

Notes: 1. The trends were calculated from the raw monthly data.

2. Discontinuities at San Francisco were found to have occurred in 1931 and 1960.

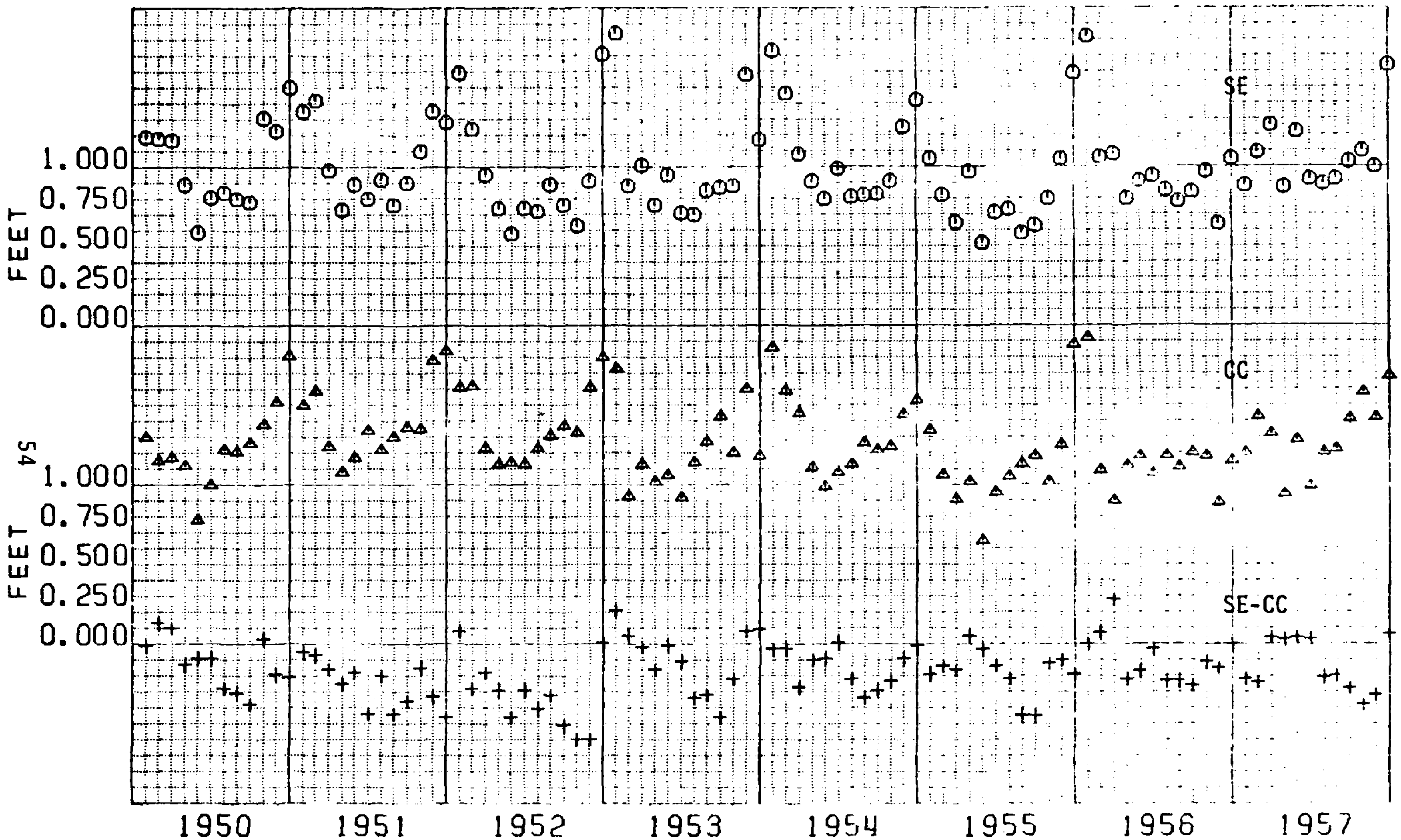

Figure 1. MEAN MONTHLY SEA LEVEL FOR SEATTLE (SE), CRESCENT CITY (CC), AND DIFFERENCES (SE-CC)

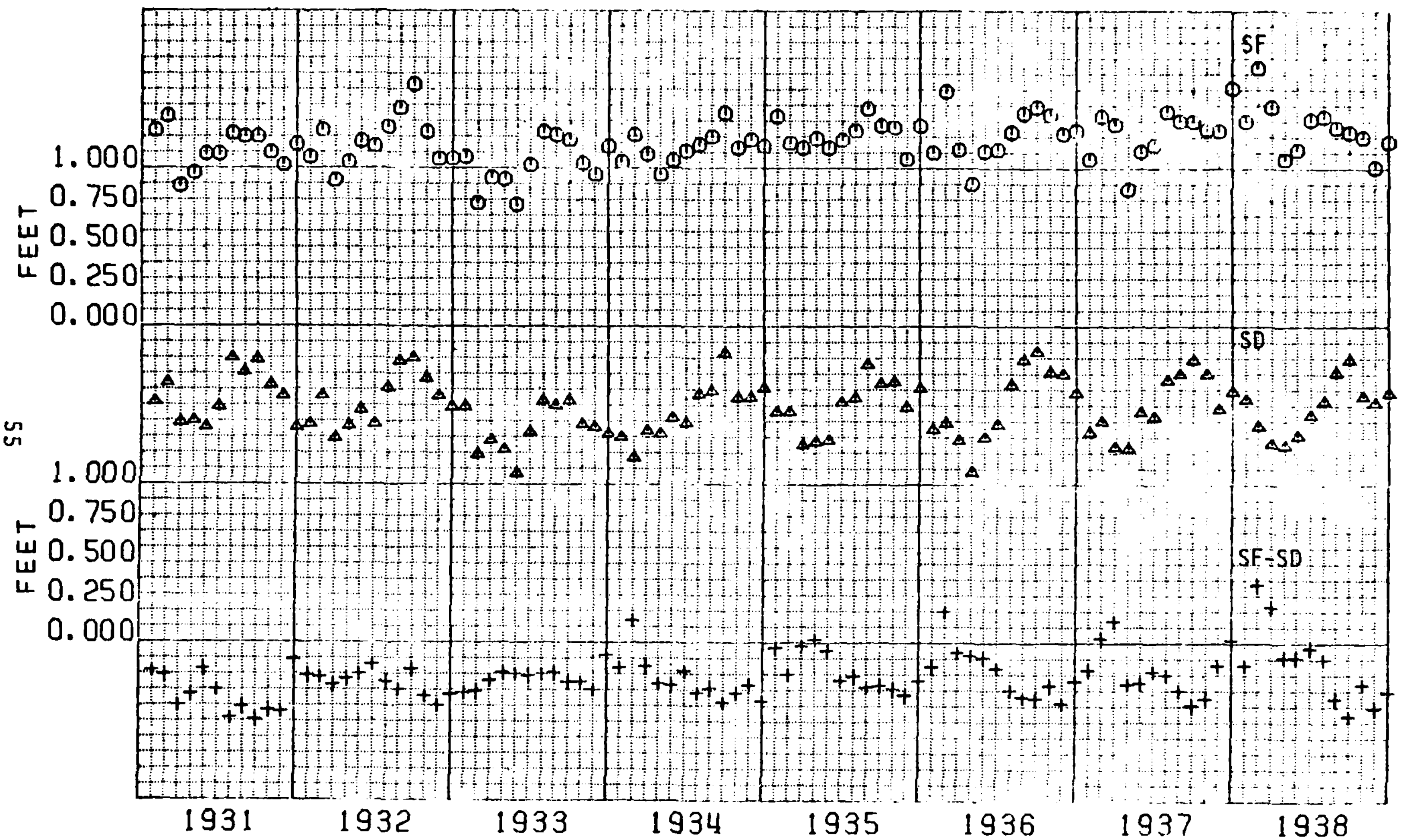

Figure 2. MEAN MONTHLY SEA LEVEL FOR SAN FRANCISCO (SF), SAN DIEGO (SD), AND DIFFERENCES (SF-SD)

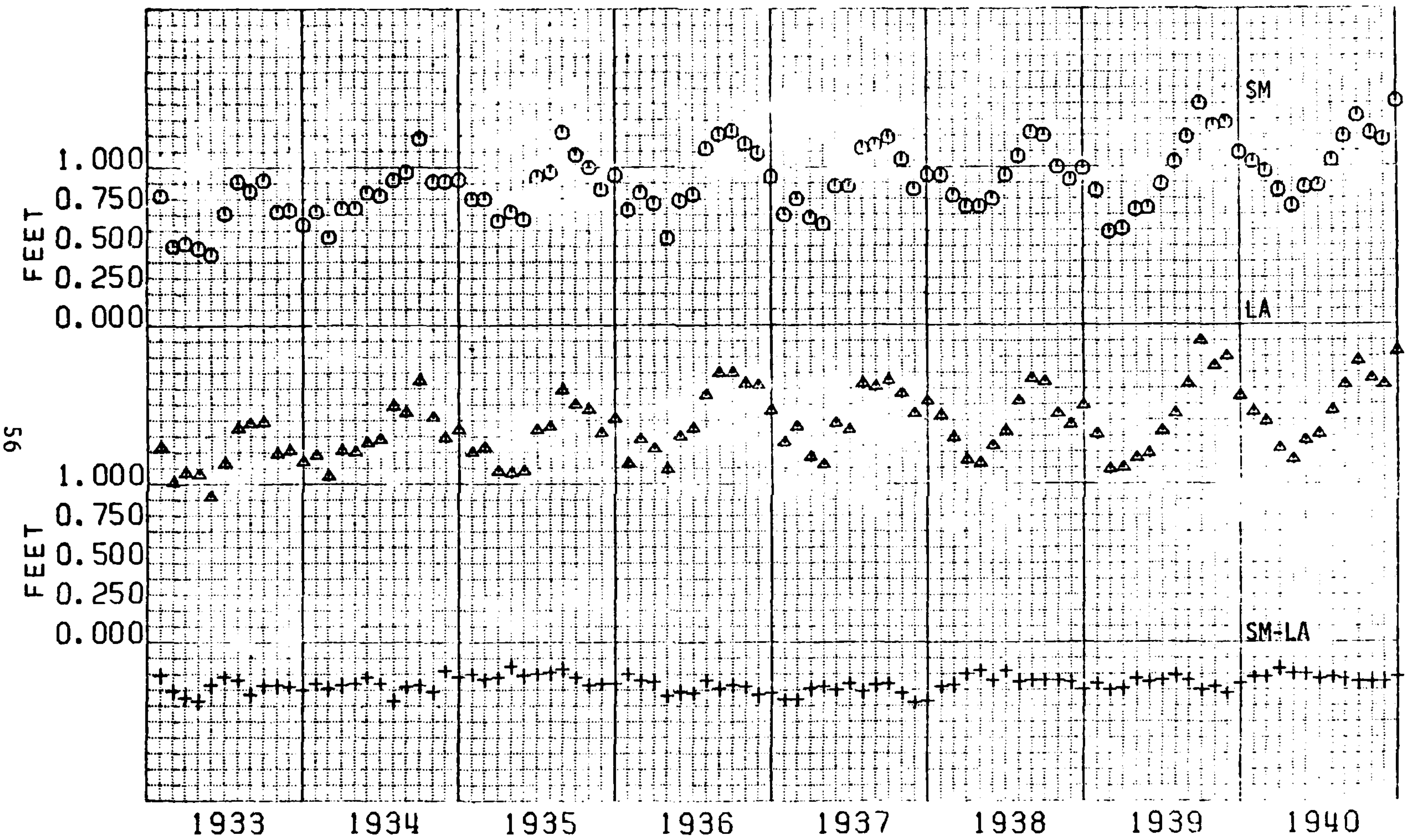

Figure 3. MEAN MONTHLY SEA LEVEL FOR SANTA MONICA (SM), LOS ANGELES (LA), AND DIFFERENCES (SM-LA)

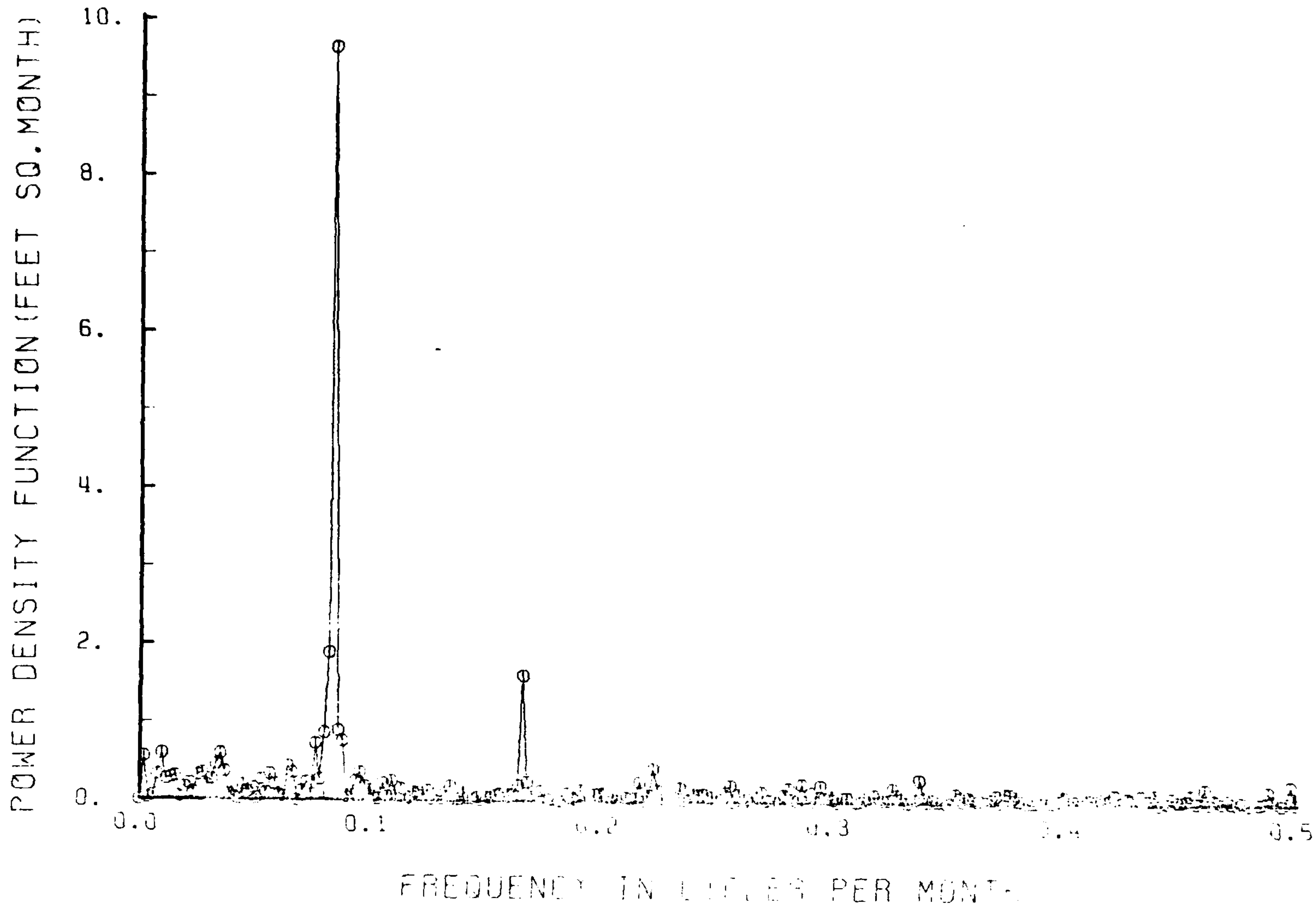

Figure 4. POWER DENSITY FUNCTION OF THE SPECTRA OF SEATTLE DATA (2 DEGREES OF FREEDOM)

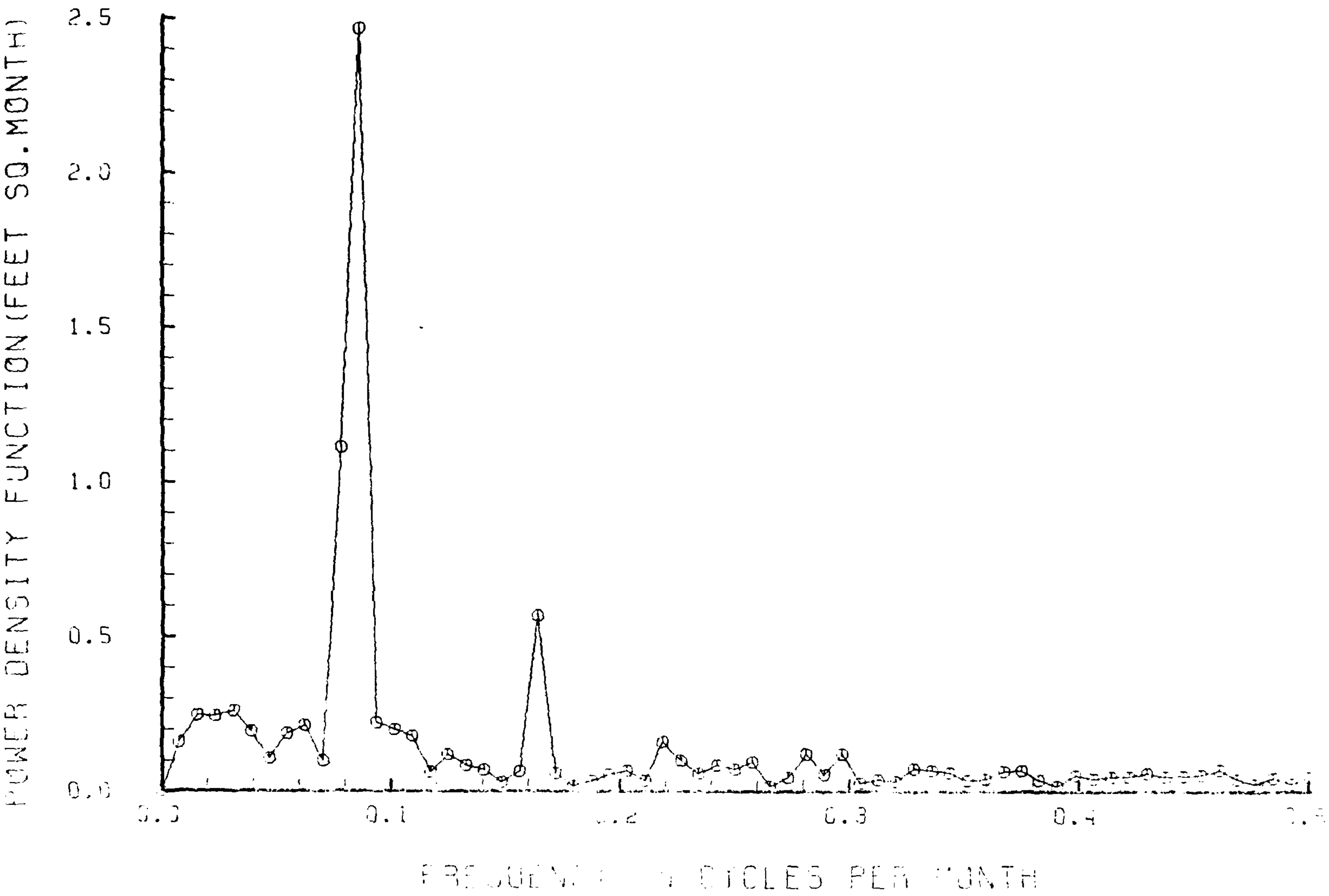

Figure 5. POWER DENSITY FUNCTION OF THE SPECRA OF SEATTLE DATA (8 DEGREES OF FREEDOM)

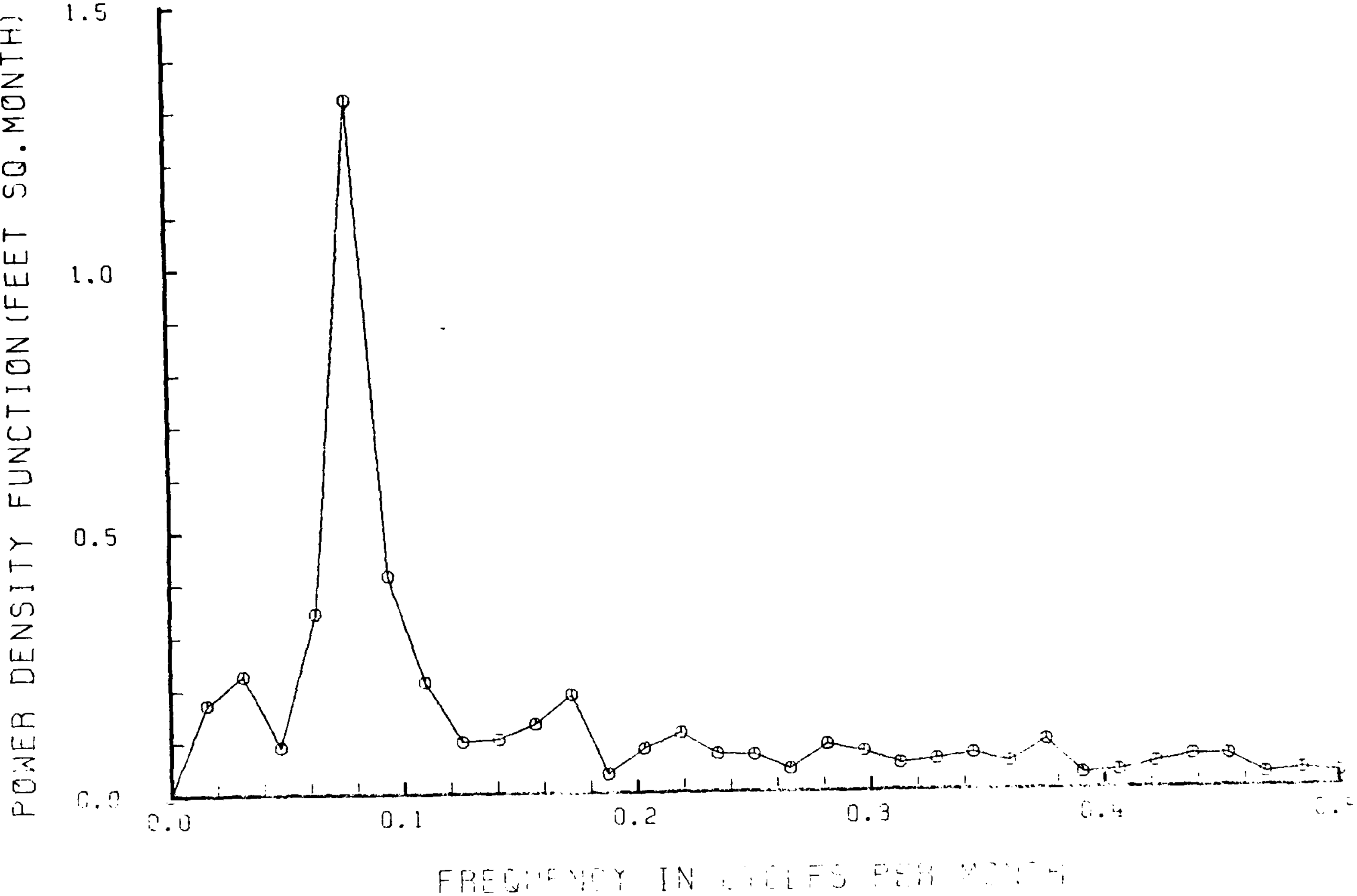

Figure 6. POWER DENSITY FUNCTION OF THE SPECTRA OF SEATTLE DATA (16 DEGREES OF FREEDOM)

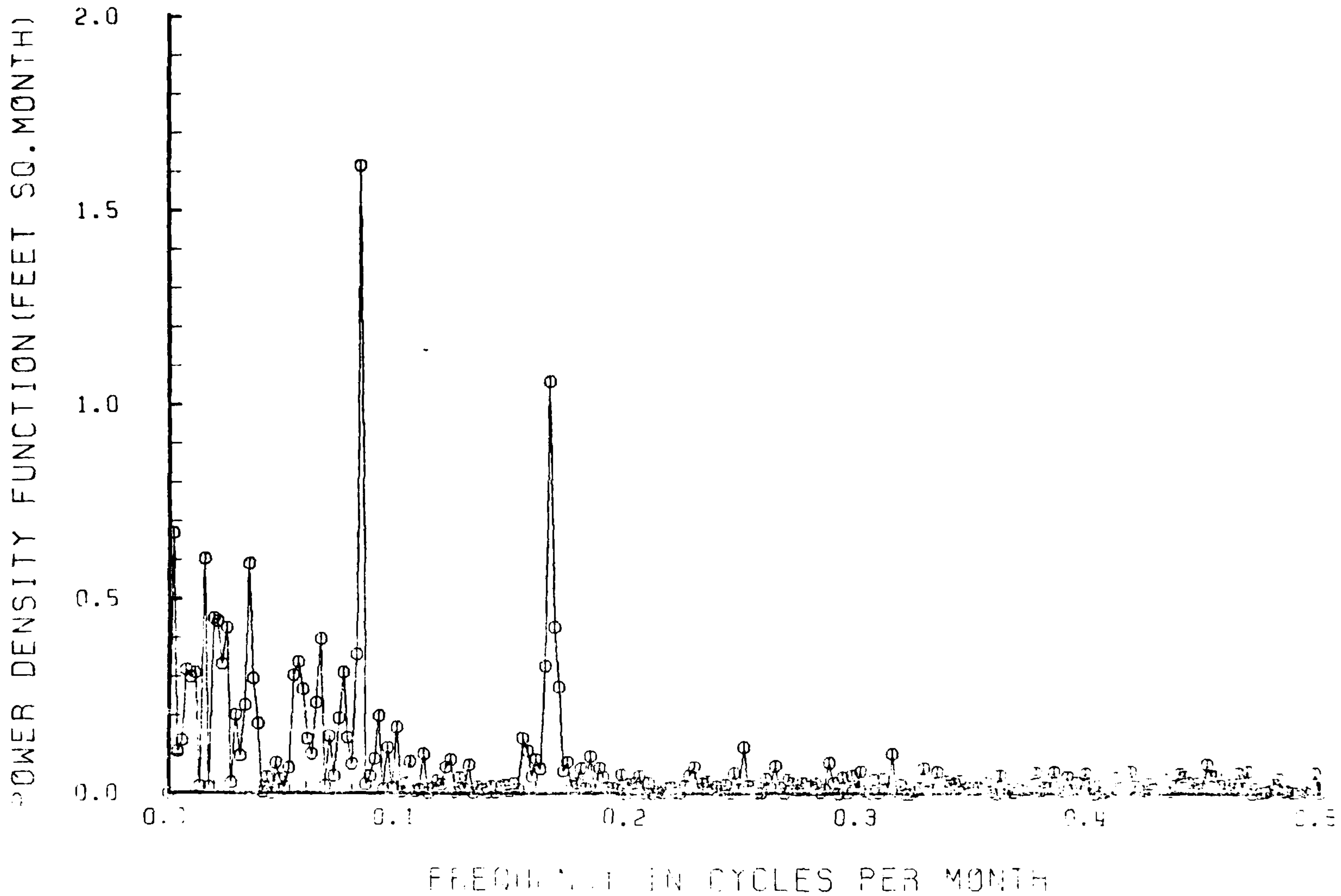

Figure 7. POWER DENSITY FUNCTION OF THE SPECTRA OF SAN FRANCISCO DATA (2 DEGREES OF FREEDOM)

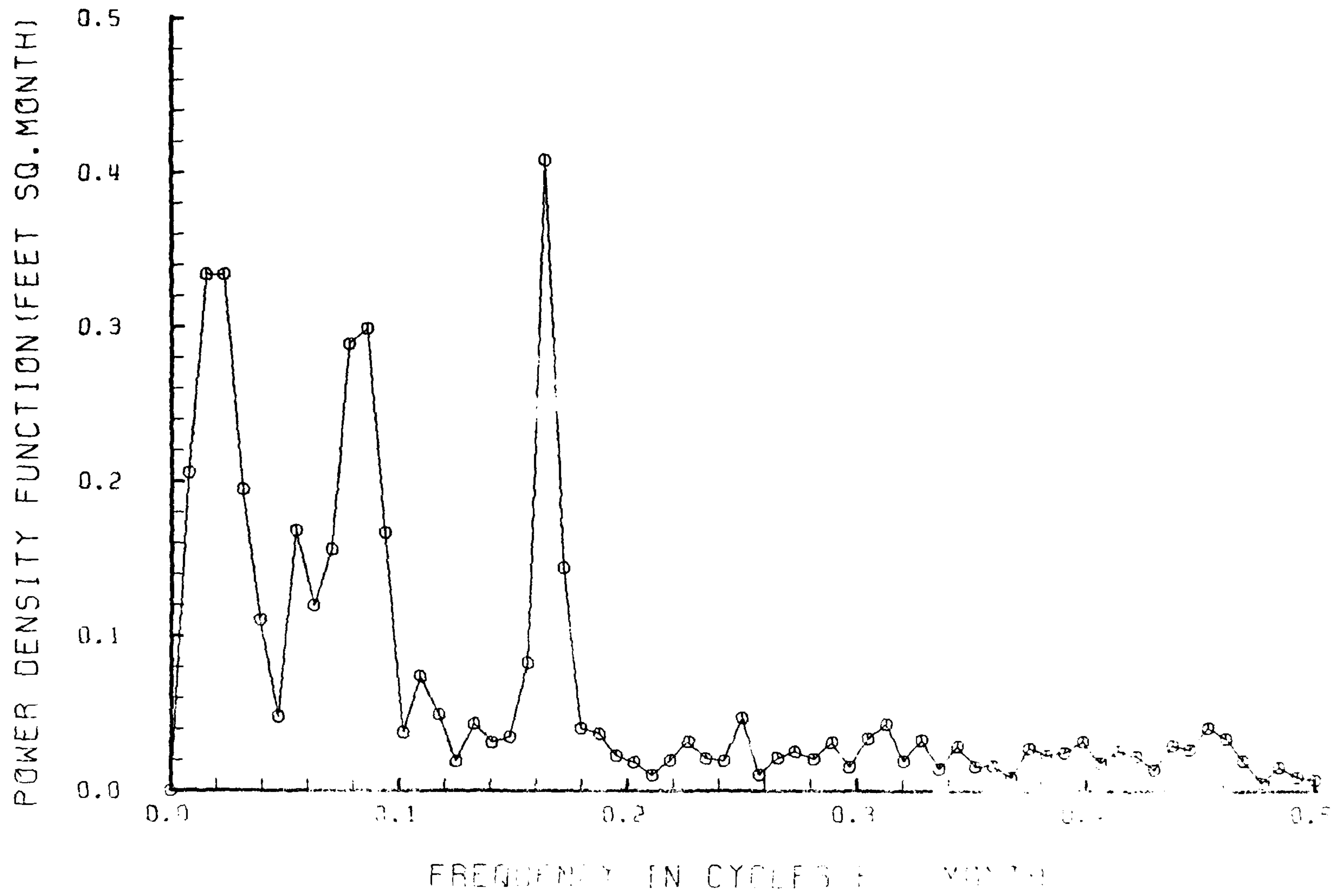

Figure 8. POWER DENSITY FUNCTION OF THE SPECTRA OF SAN FRANCISCO DATA (8 DEGREES OF FREEDOM)

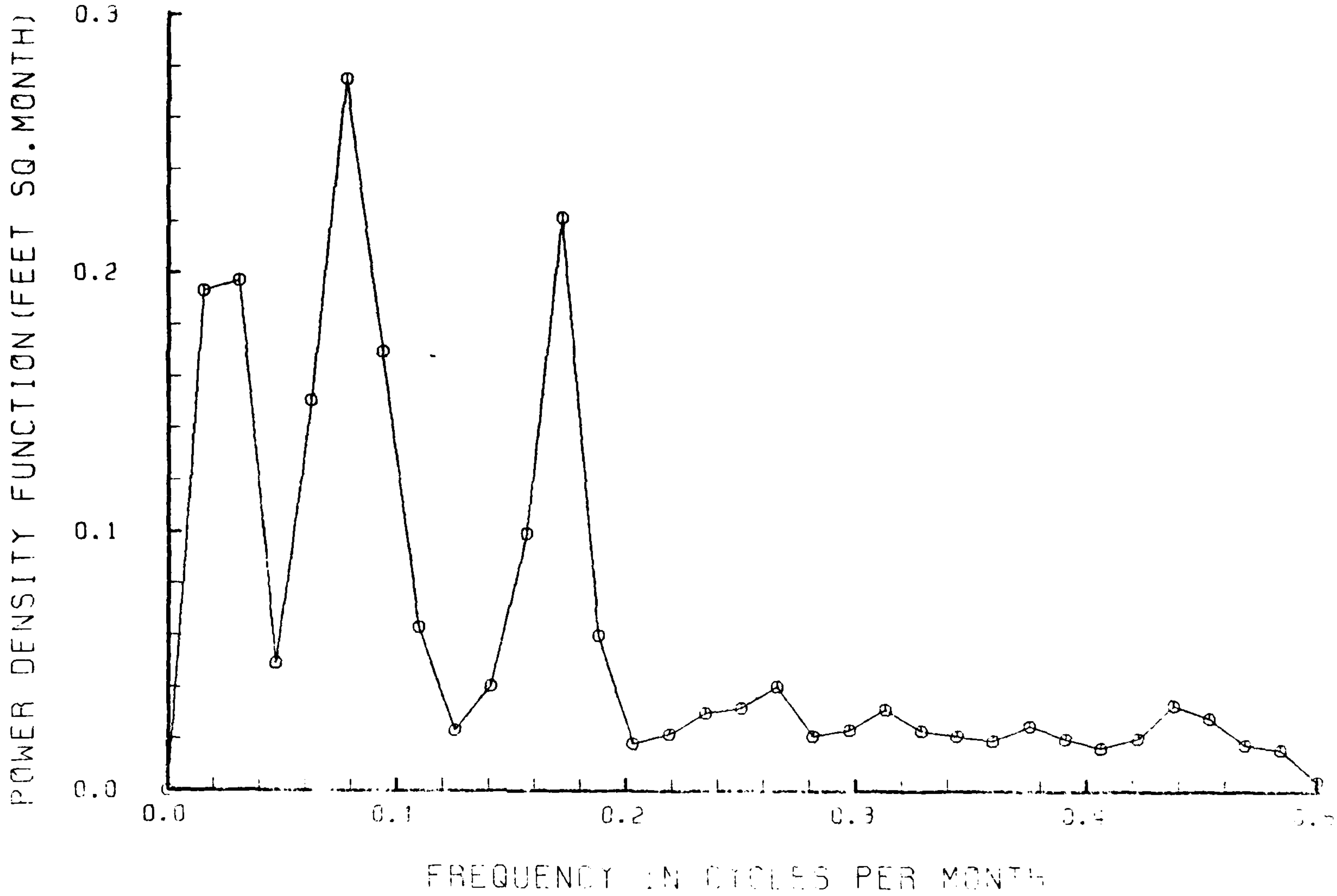

Figure 9. POWER DENSITY FUNCTION OF THE SPECTRA OF SAN FRANCISCO DATA (16 DEGREES OF FREEDOM)

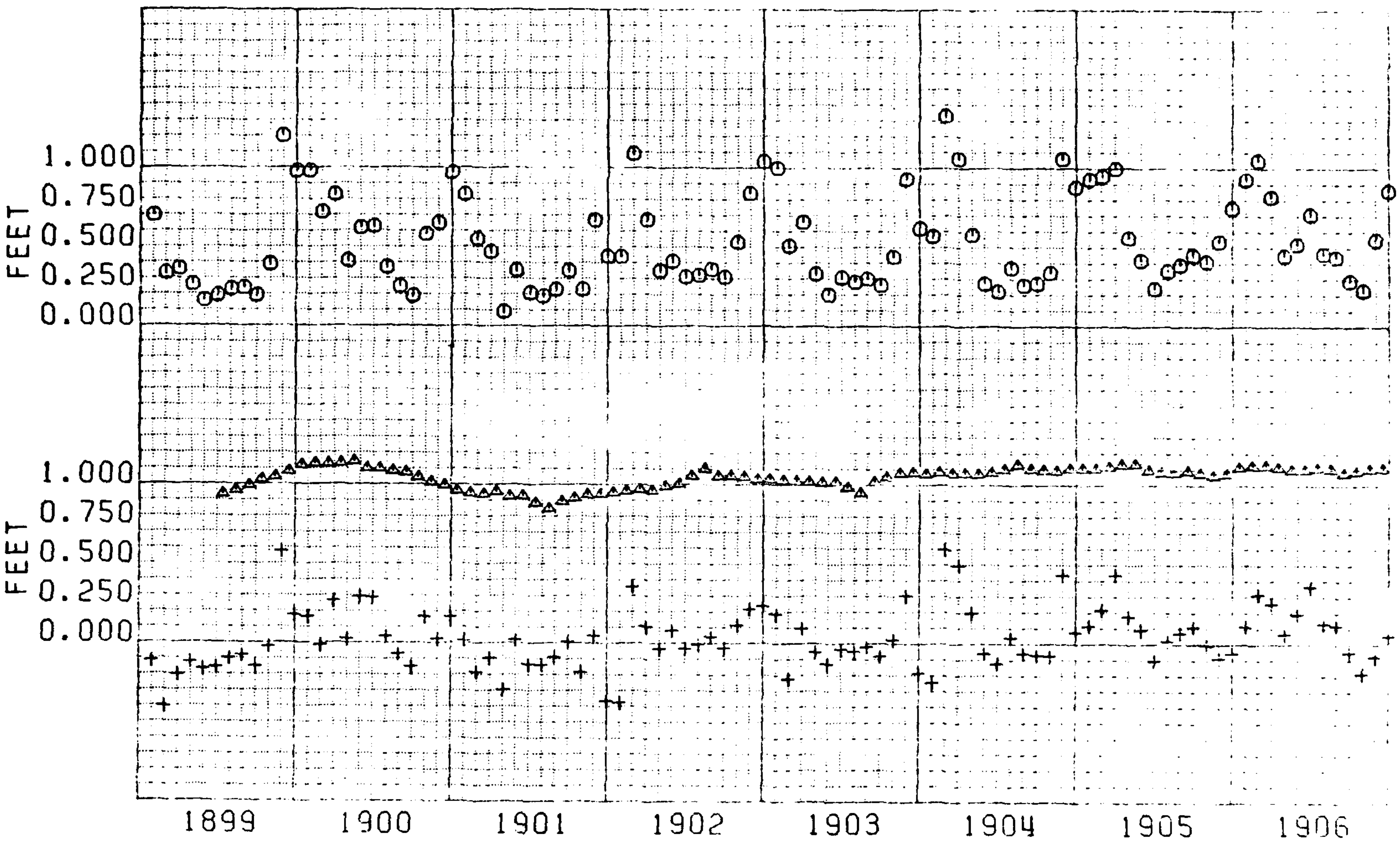

Figure 10. RAW DATA, 12 MONTH RUNNING MEANS, AND ANOMALIES FOR SEATTLE

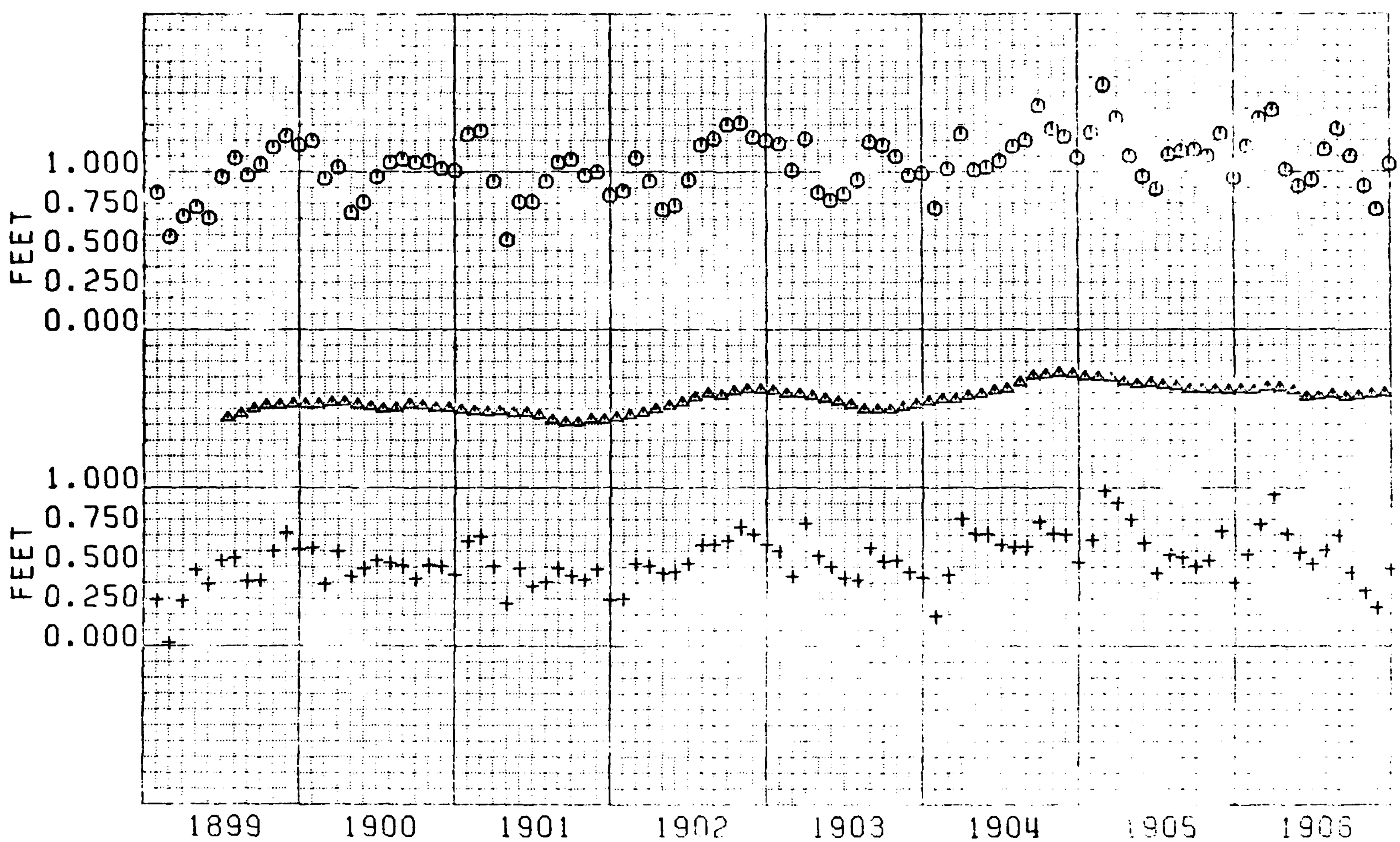

Figure 11. RAW DATA, 12 MONTH RUNNING MEANS, AND ANOMALIES FOR SAN FRANCISCO

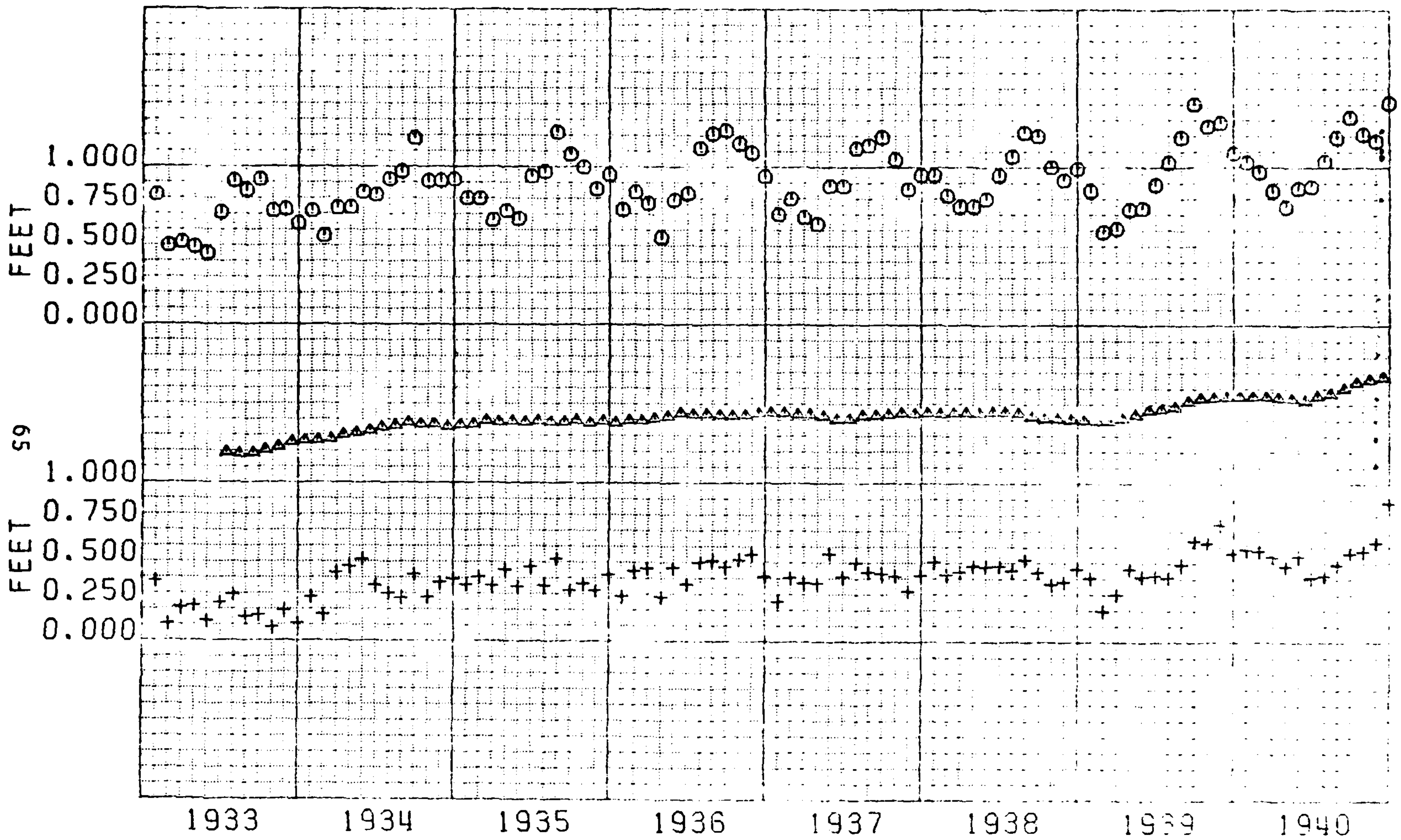

Figure 12. RAW DATA, 12 MONTH RUNNING MEANS, AND ANOMALIES FOR SANTA MONICA

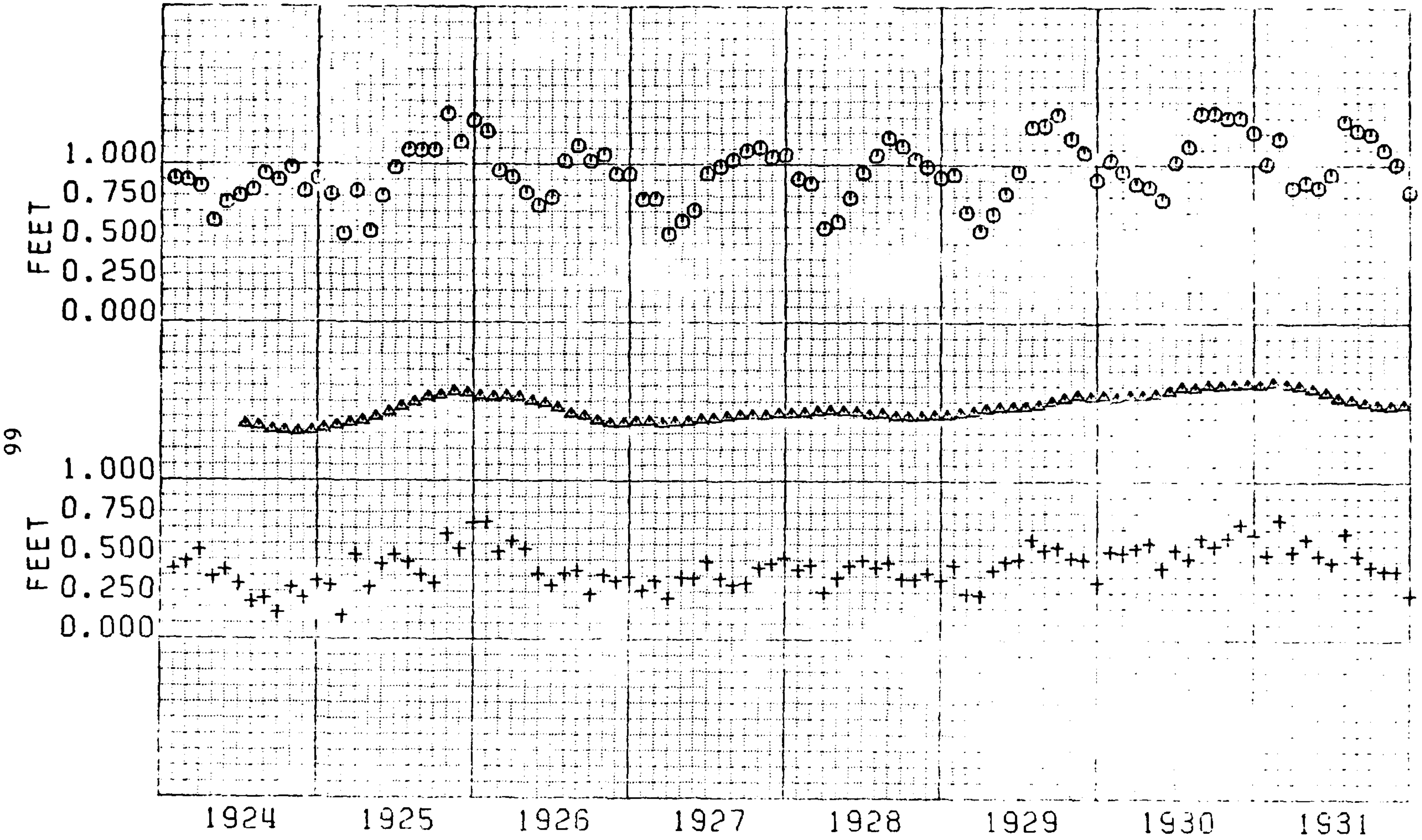

Figure 13. RAW DATA, 12 MONTH RUNNING MEANS, AND ANOMALIES FOR LOS ANGELES

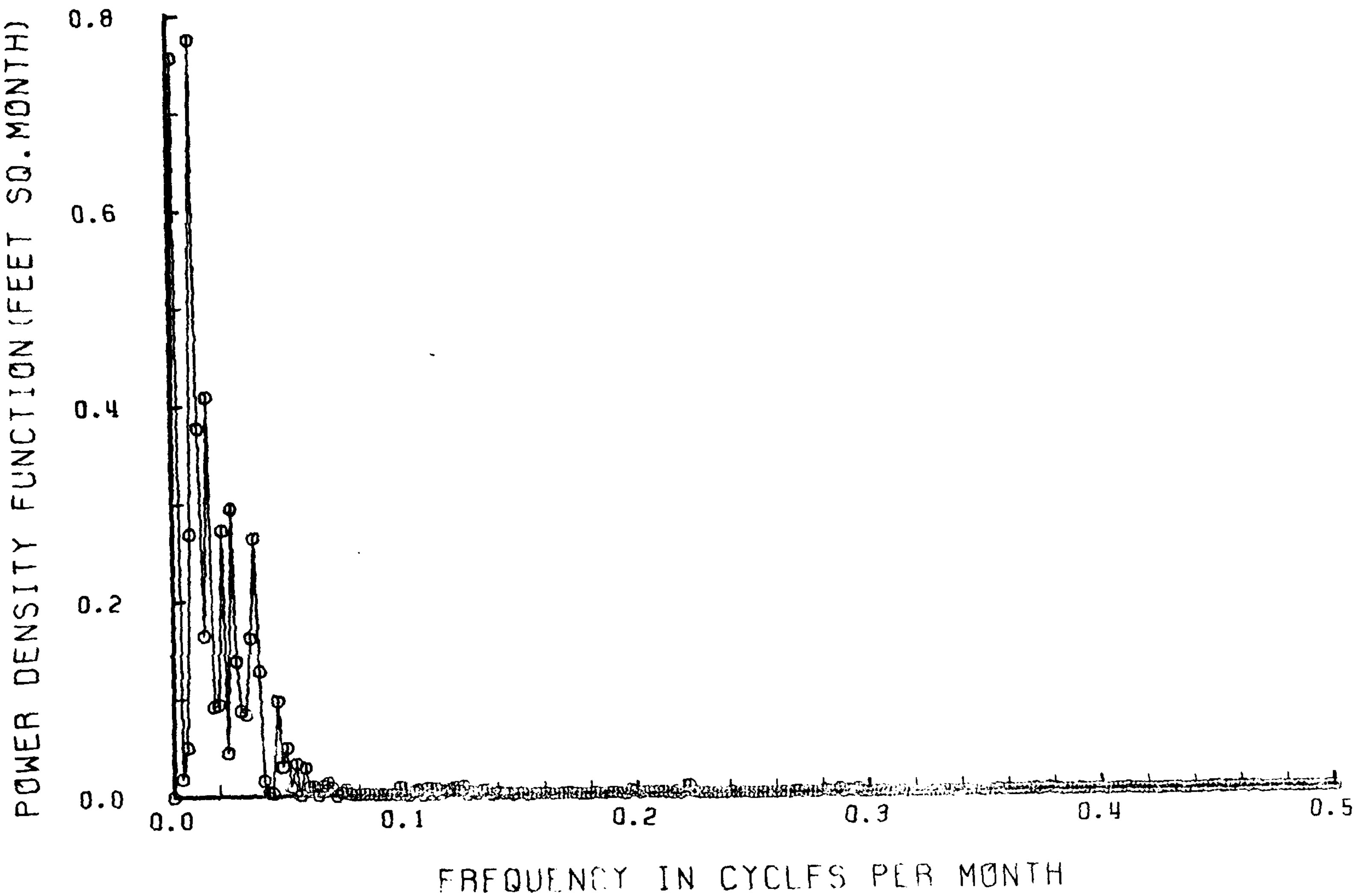

Figure 14. POWER DENSITY FUNCTION OF THE SPECTRA OF 12 MO. R. M.—SEATTLE (2 DEGREES OF FREEDOM)

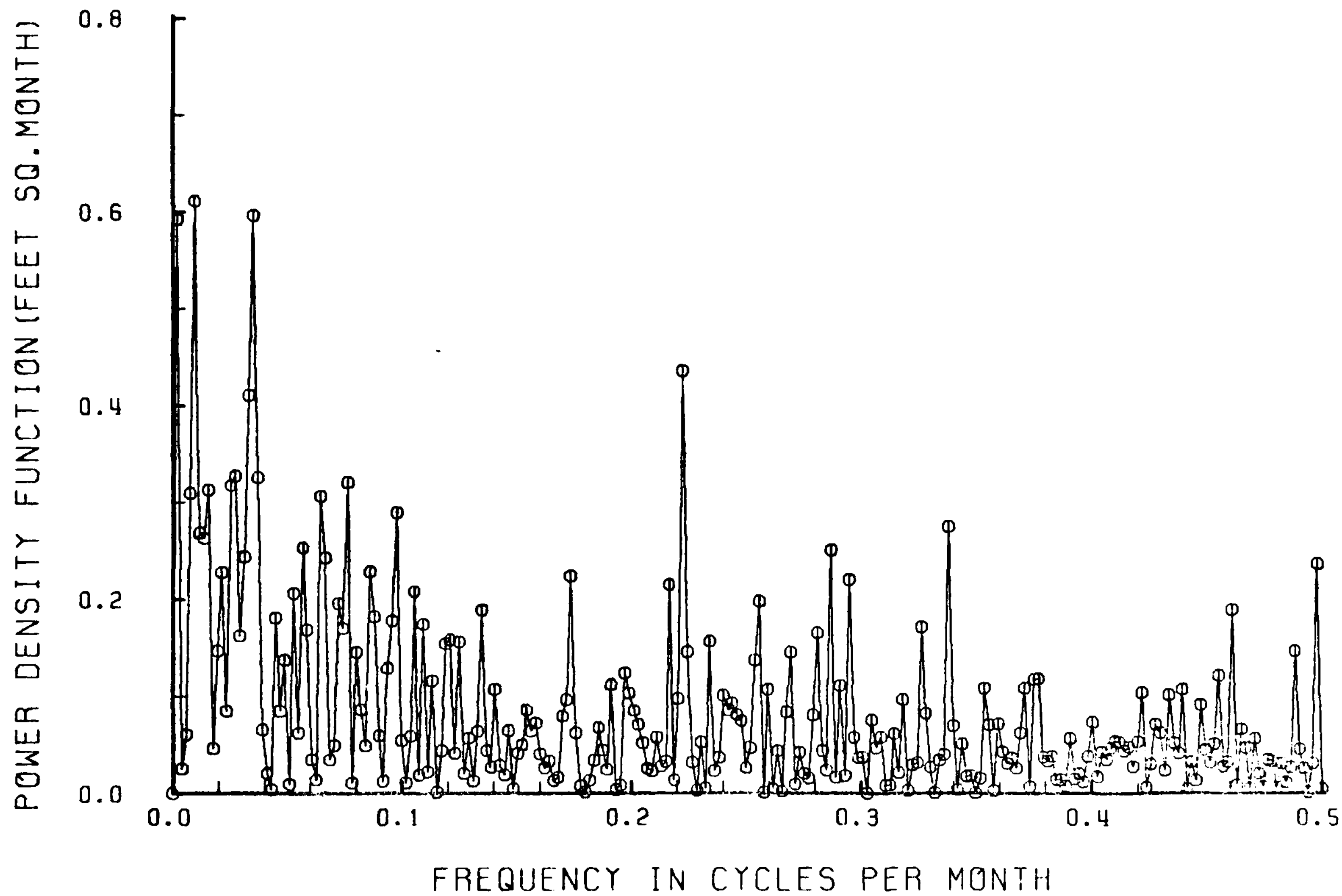

Figure 15. POWER DENSITY FUNCTION OF THE SPECTRA OF ANOMALIES-SEATTLE (2 DEGREES OF FREEDOM)

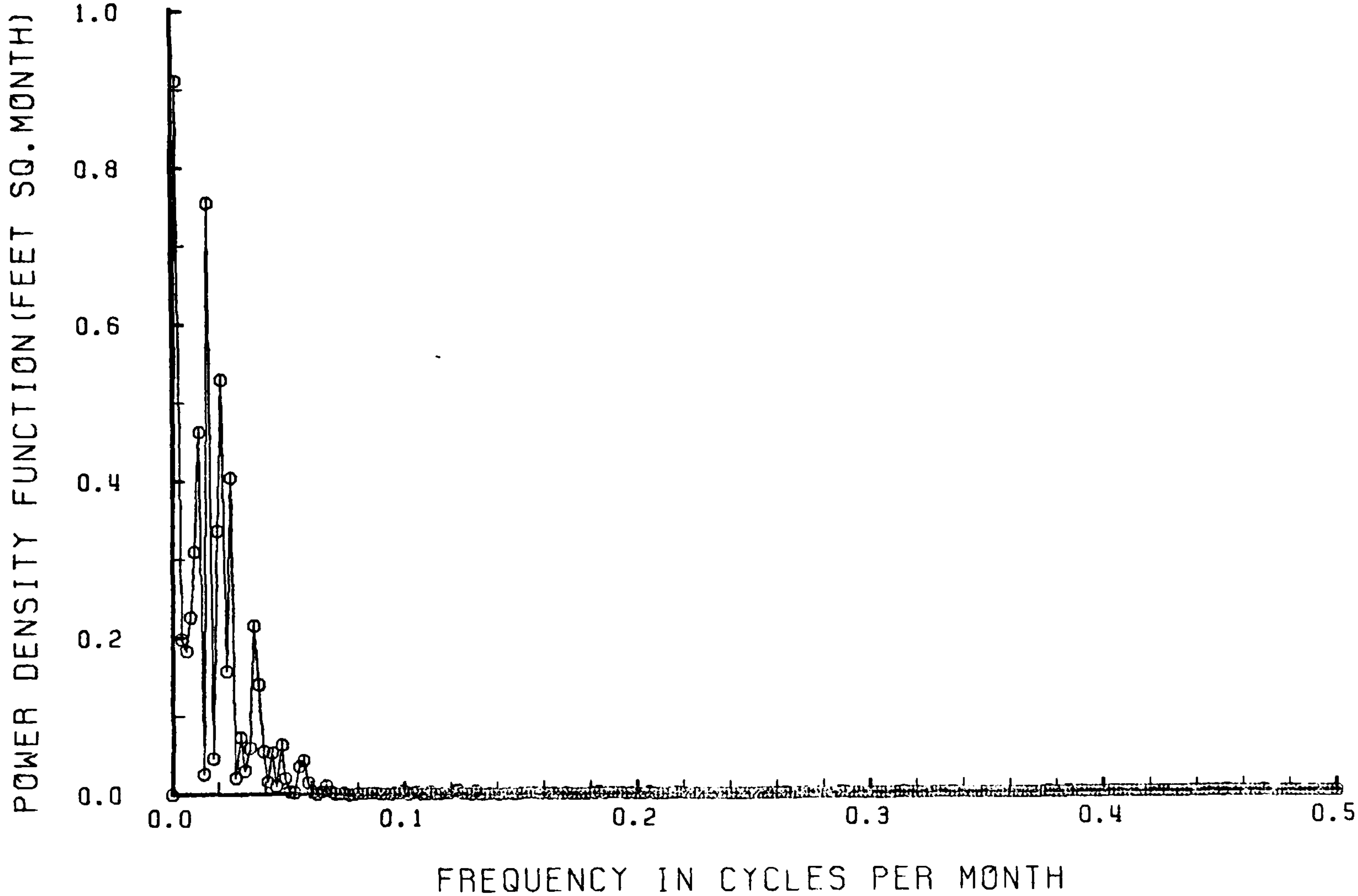

Figure 16. POWER DENSITY FUNCTION OF THE SPECTRA OF 12 MO. R. M.-SAN FRANCISCO (2 DEGREES OF FREEDOM)

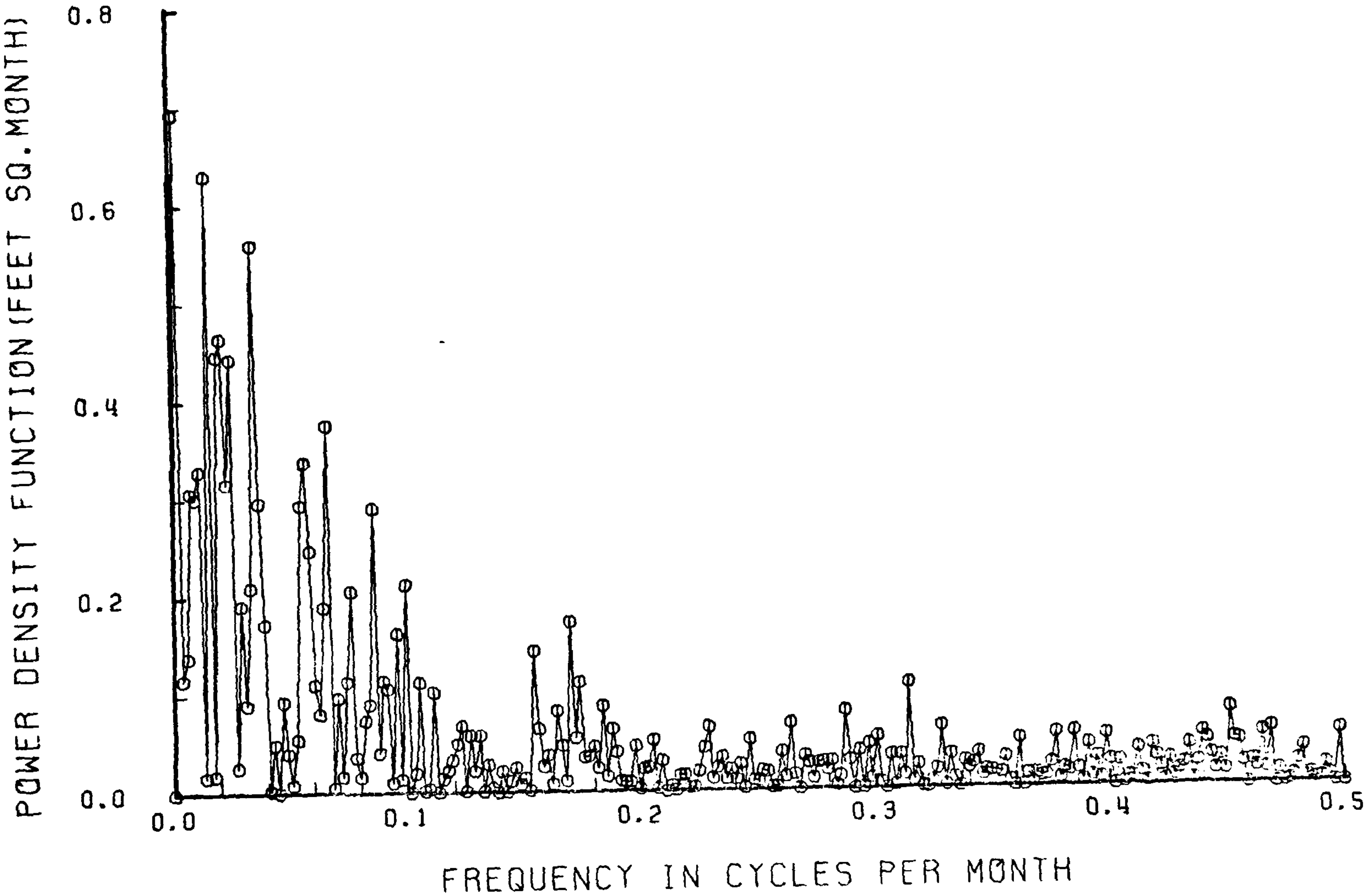

Figure 17. POWER DENSITY FUNCTION OF THE SPECTRA OF ANOMALIES-SAN FRANCISCO (2 DEGREES OF FREEDOM)

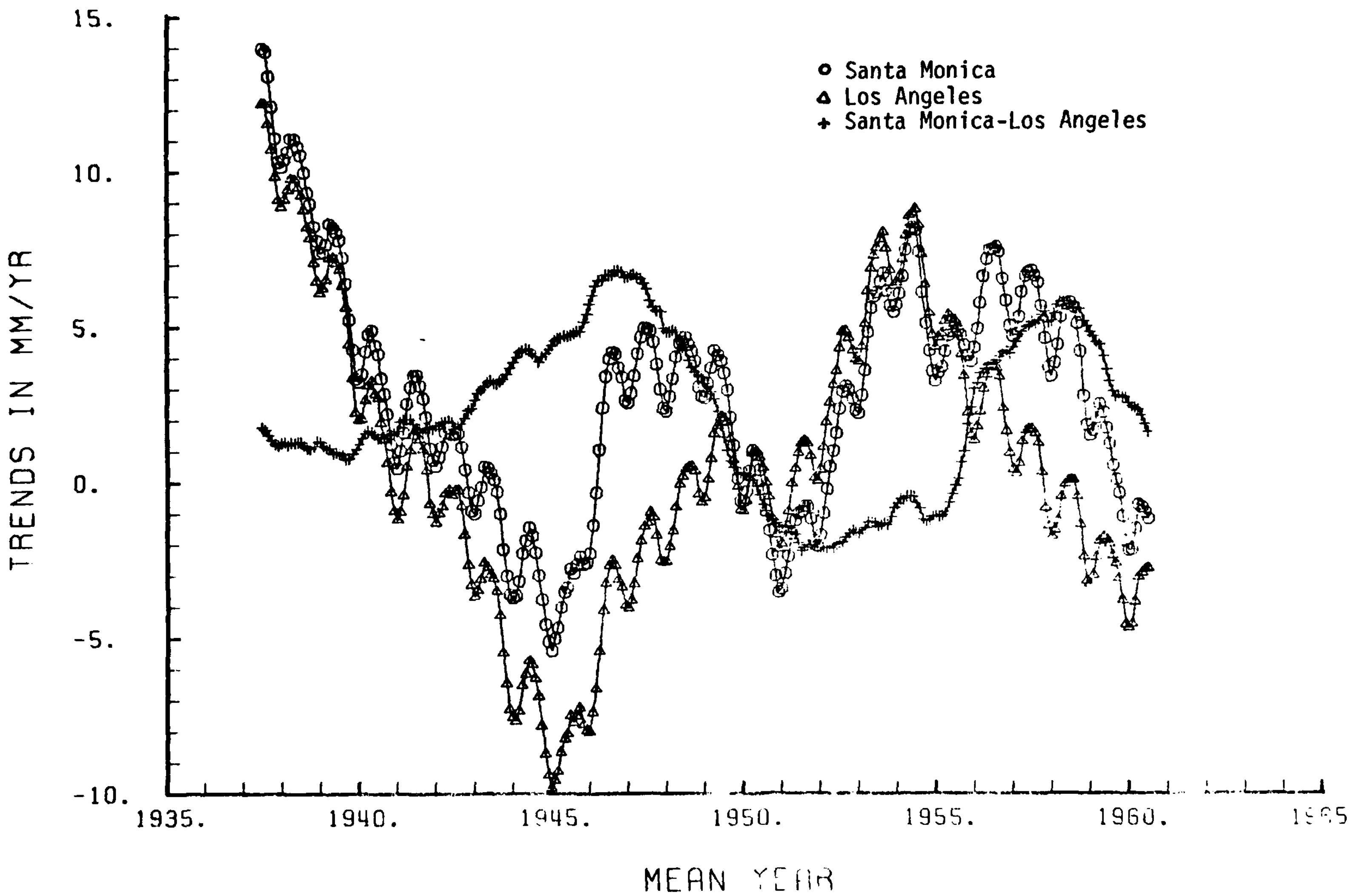

Figure 18. TRENDS OF THE RAW DATA FOR SM, LA, AND (SM-LA) USING A 10-YEAR WINDOW

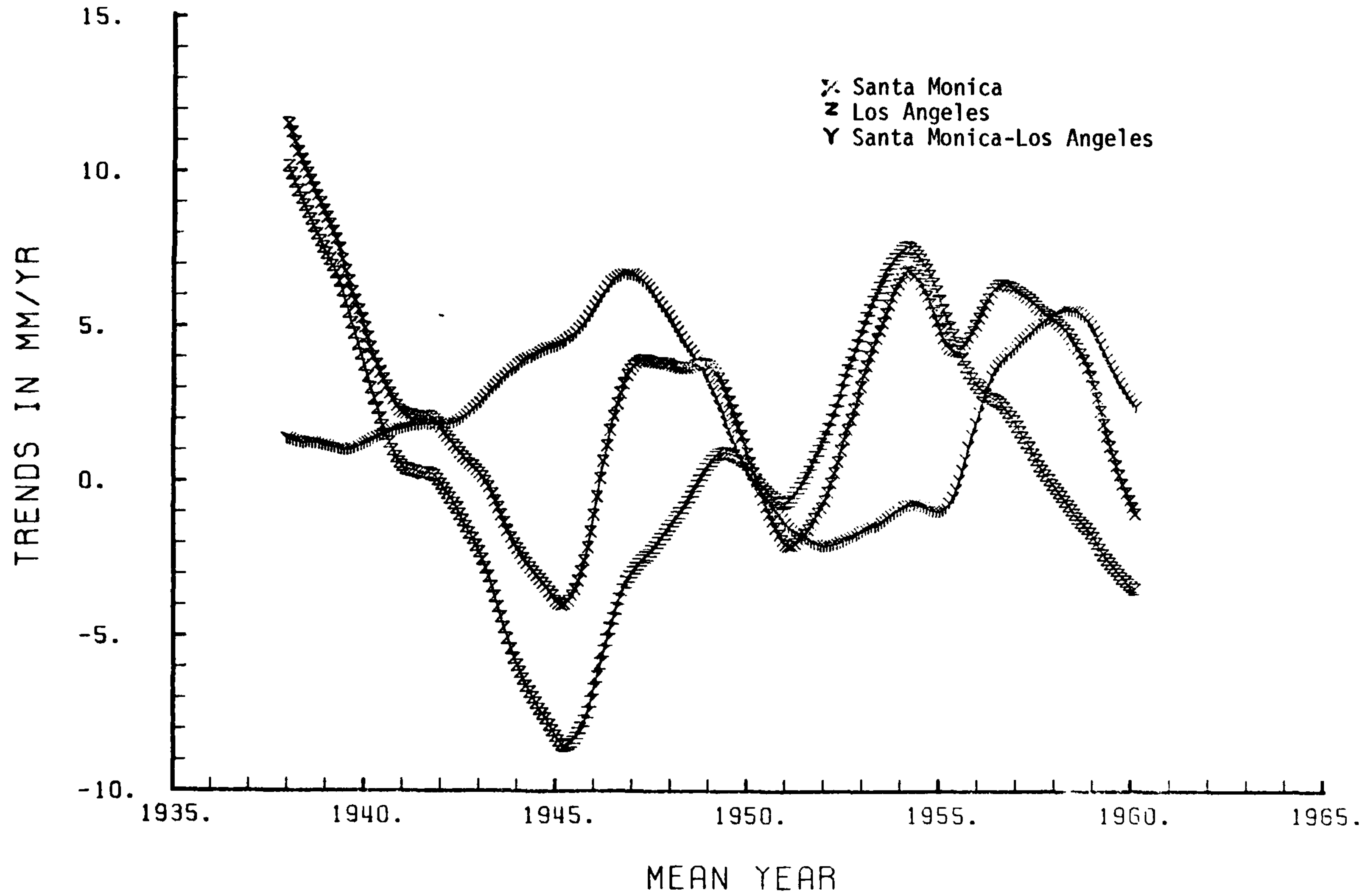

Figure 19. TRENDS OF 12 MONTH RUNNING MEANS FOR SM, LA, AND (SM-LA) USING A 10-YEAR WINDOW

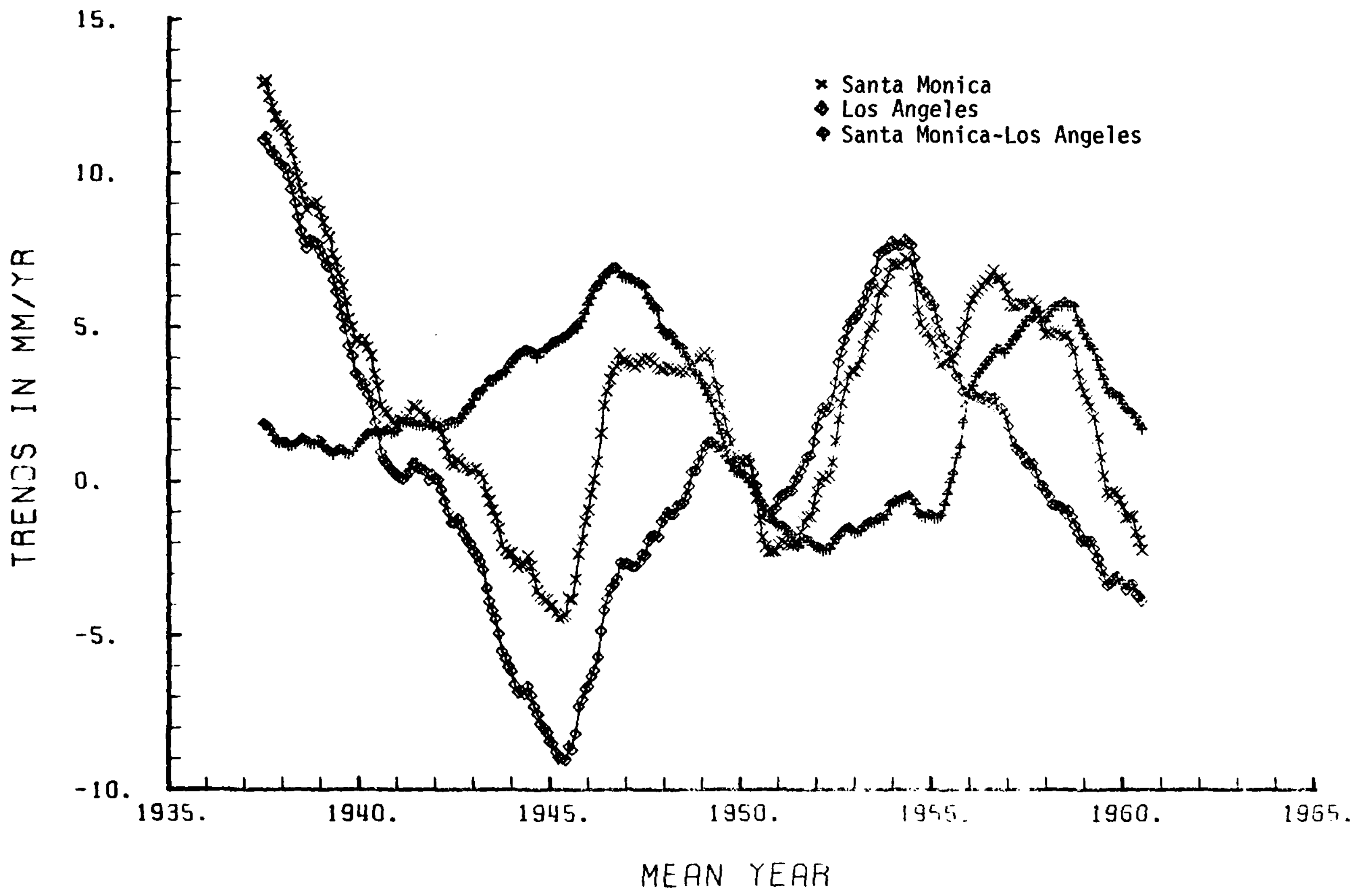

Figure 20. TRENDS OF ANOMALIES FOR SM, LA, AND (SM-LA) USING A 10-YEAR WINDOW

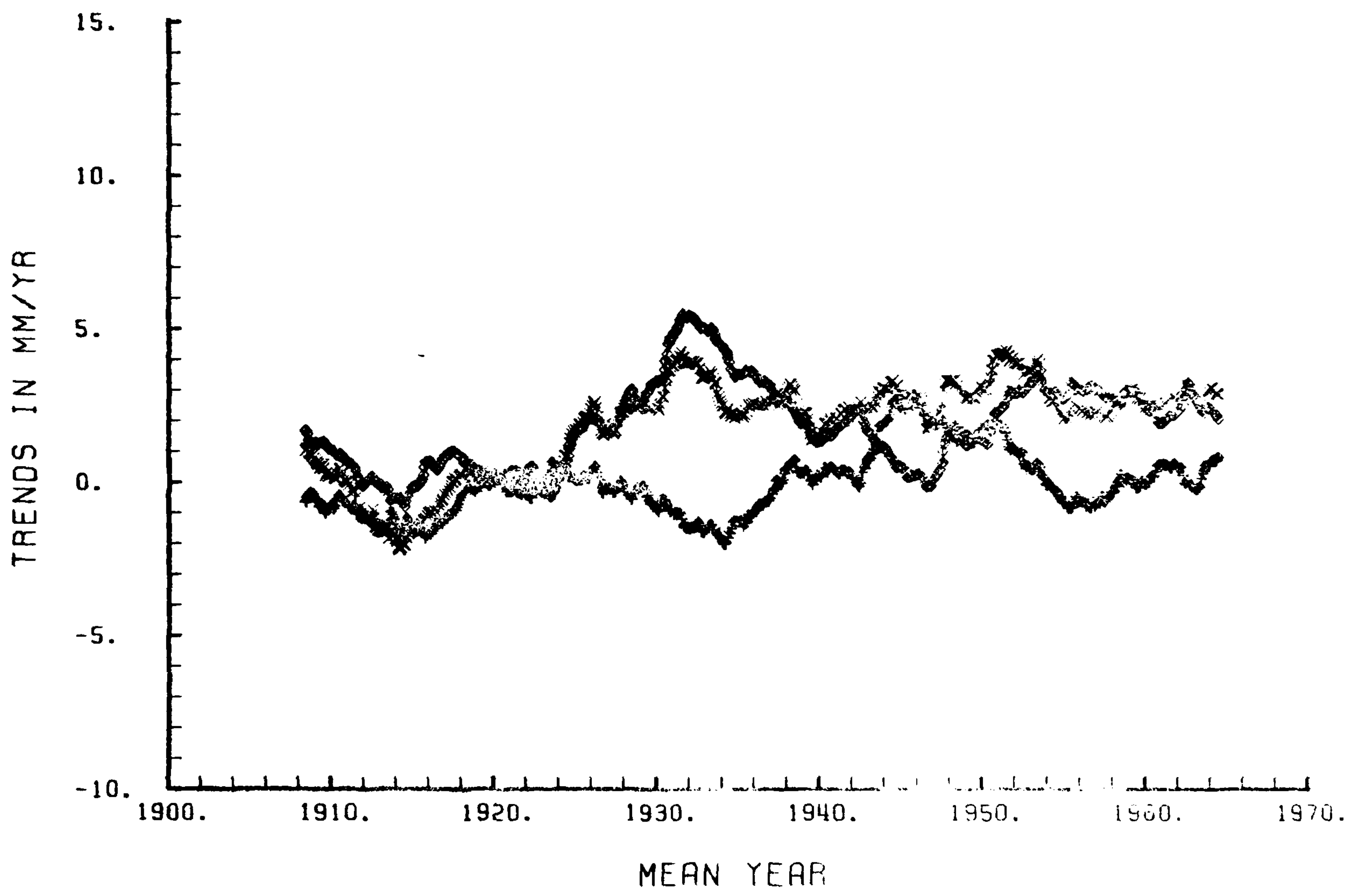

Figure 21. TRENDS OF ANOMALIES FOR SE, SF, AND (SE-SF) USING A 20-YEAR WINDOW

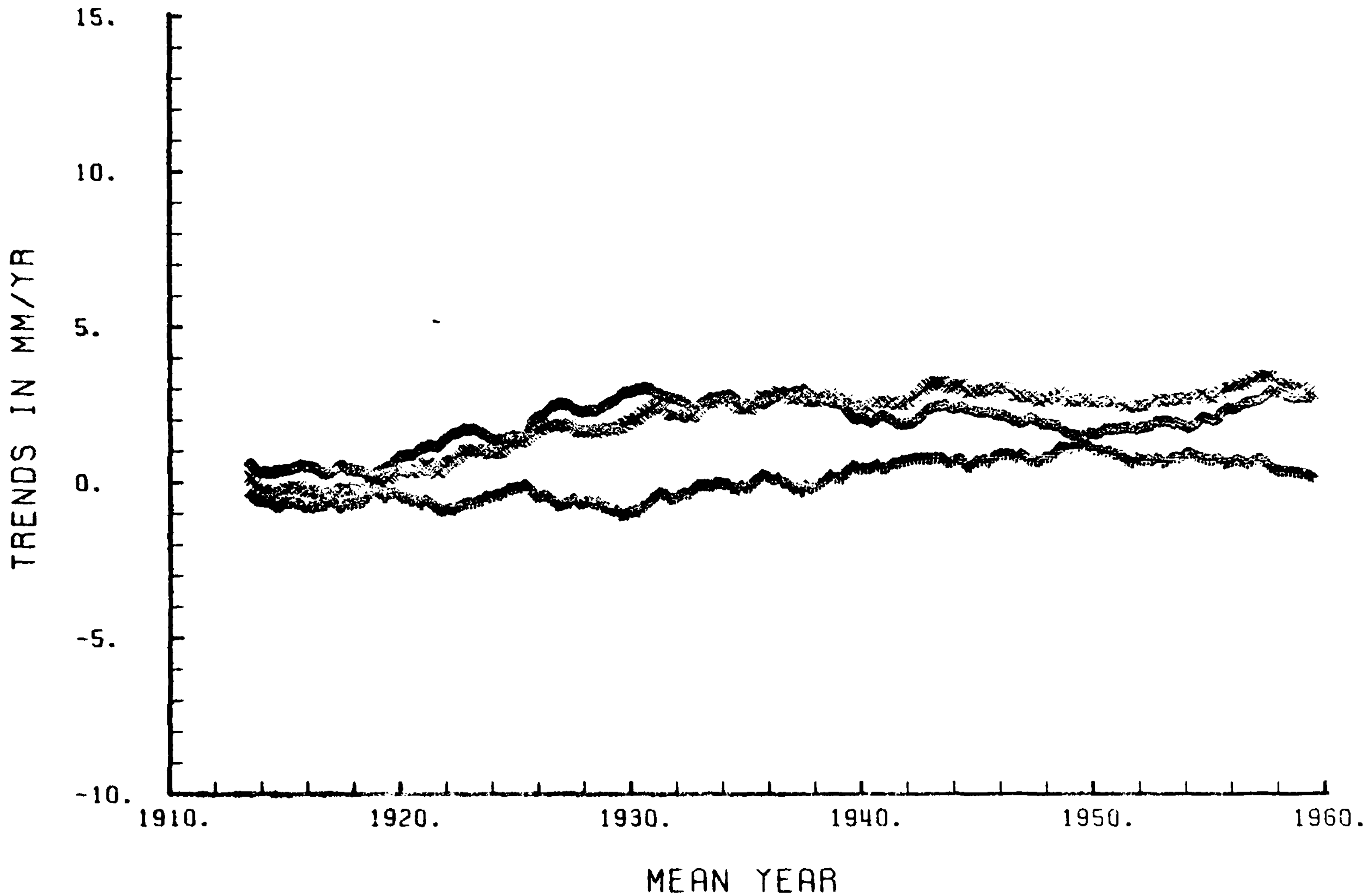

Figure 22. TRENDS OF ANOMALIES FOR SE, SF, AND (SE-SF) USING A 30-YEAR WINDOW

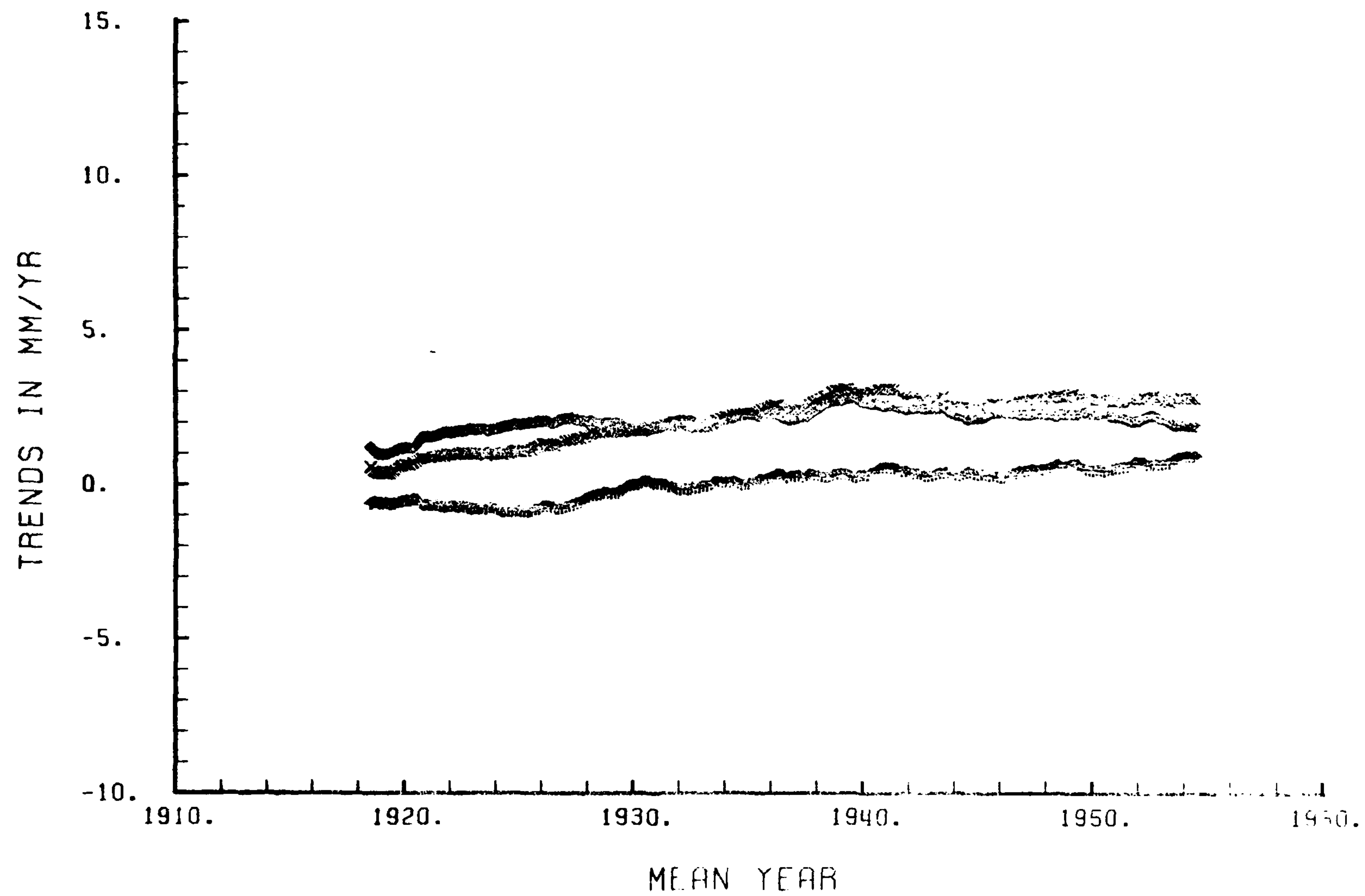

Figure 23. TRENDS OF ANOMALIES FOR SE, SF, AND (SE-SF) USING A 40-YEAR WINDOW

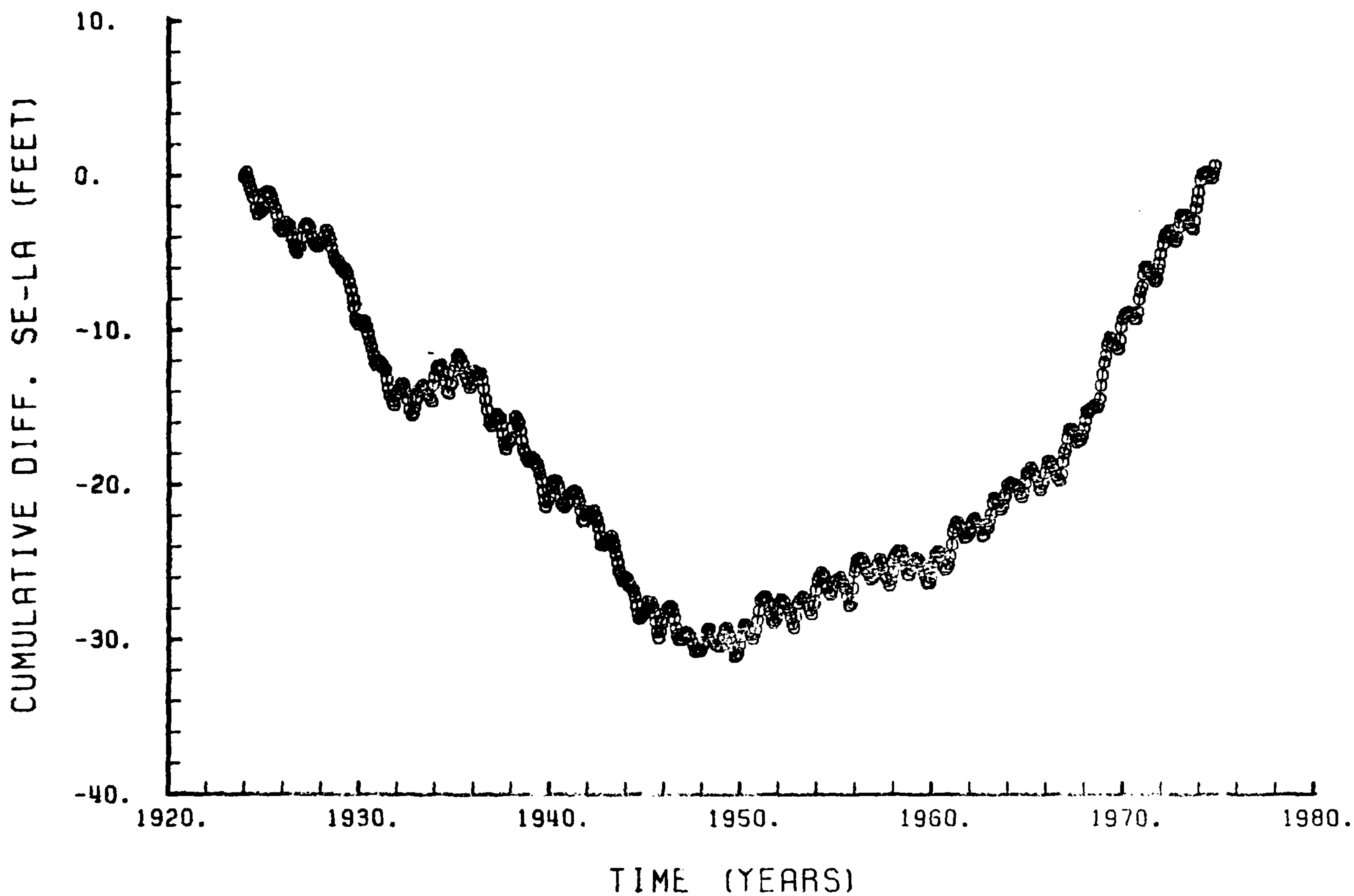

Figure 24. CUMULATIVE DIFFERENCES (SE-LA) USING RAW DATA AND MATCHING THE STATION MEANS

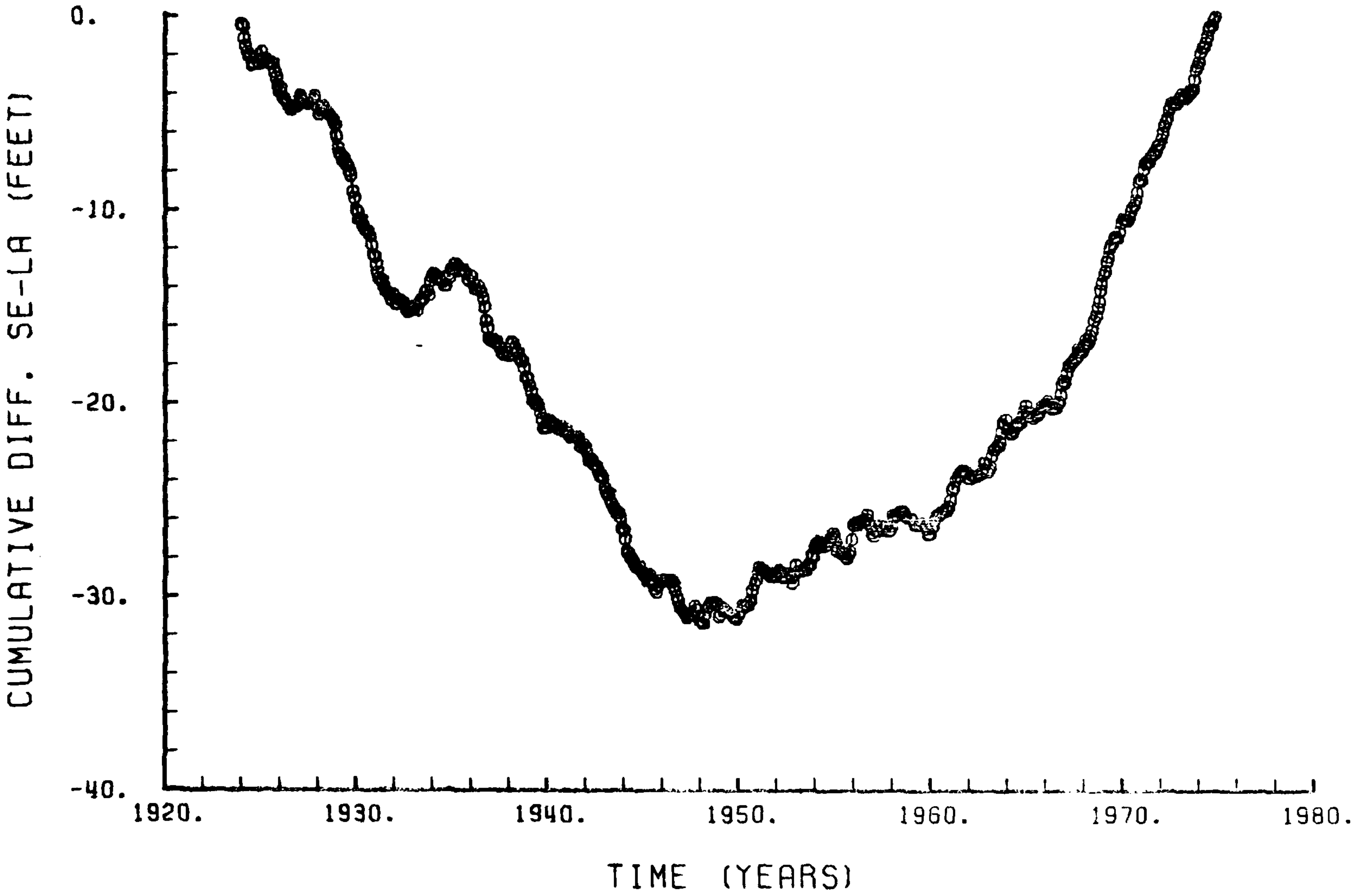

Figure 25. CUMULATIVE DIFFERENCES (SE-LA) USING ANOMALIES AND MATCHING THE STATION MEANS

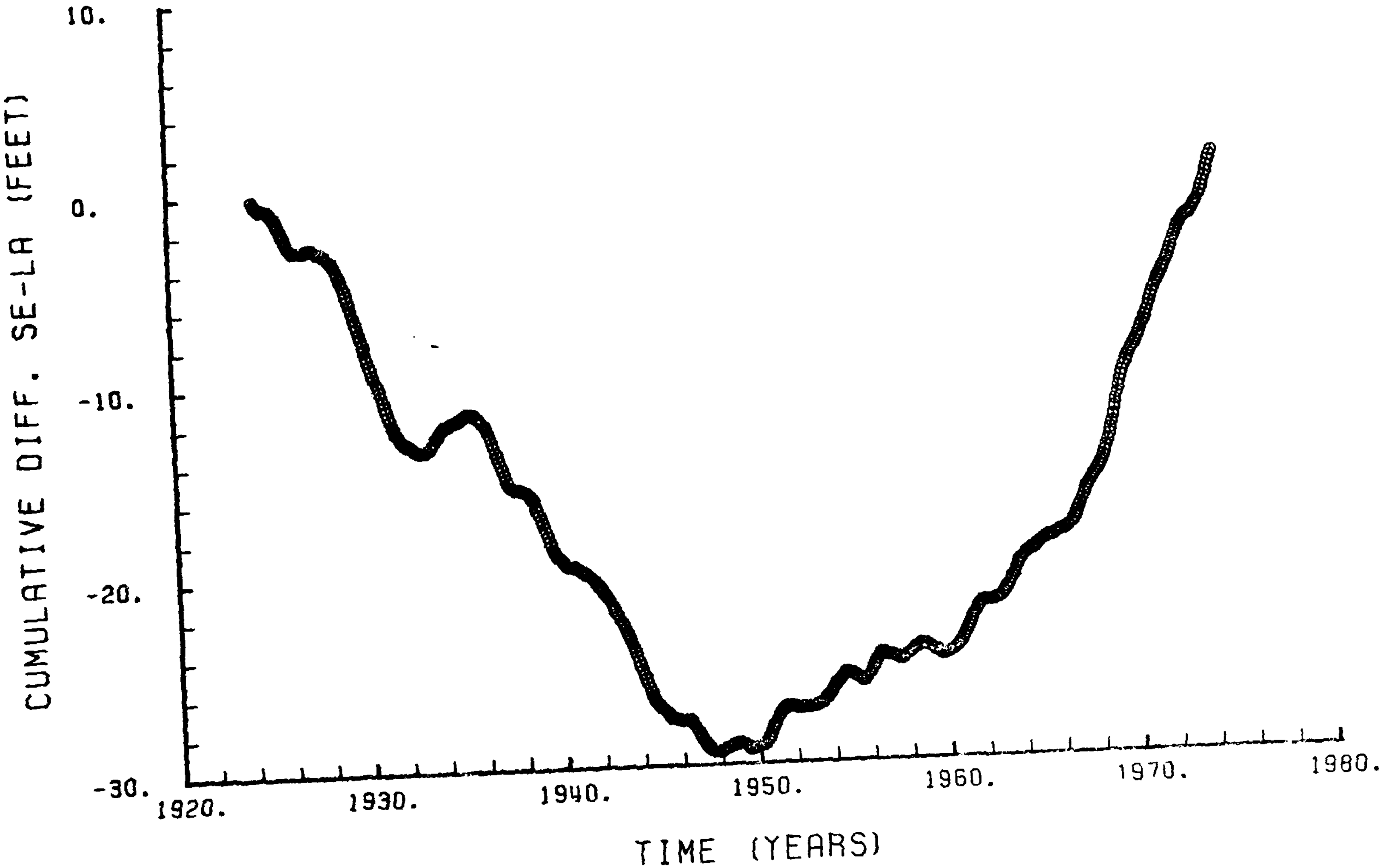

Figure 26. CUMULATIVE DIFFERENCES (SE-LA) USING 12 MO. R. M. AND MATCHING THE STATION MEANS

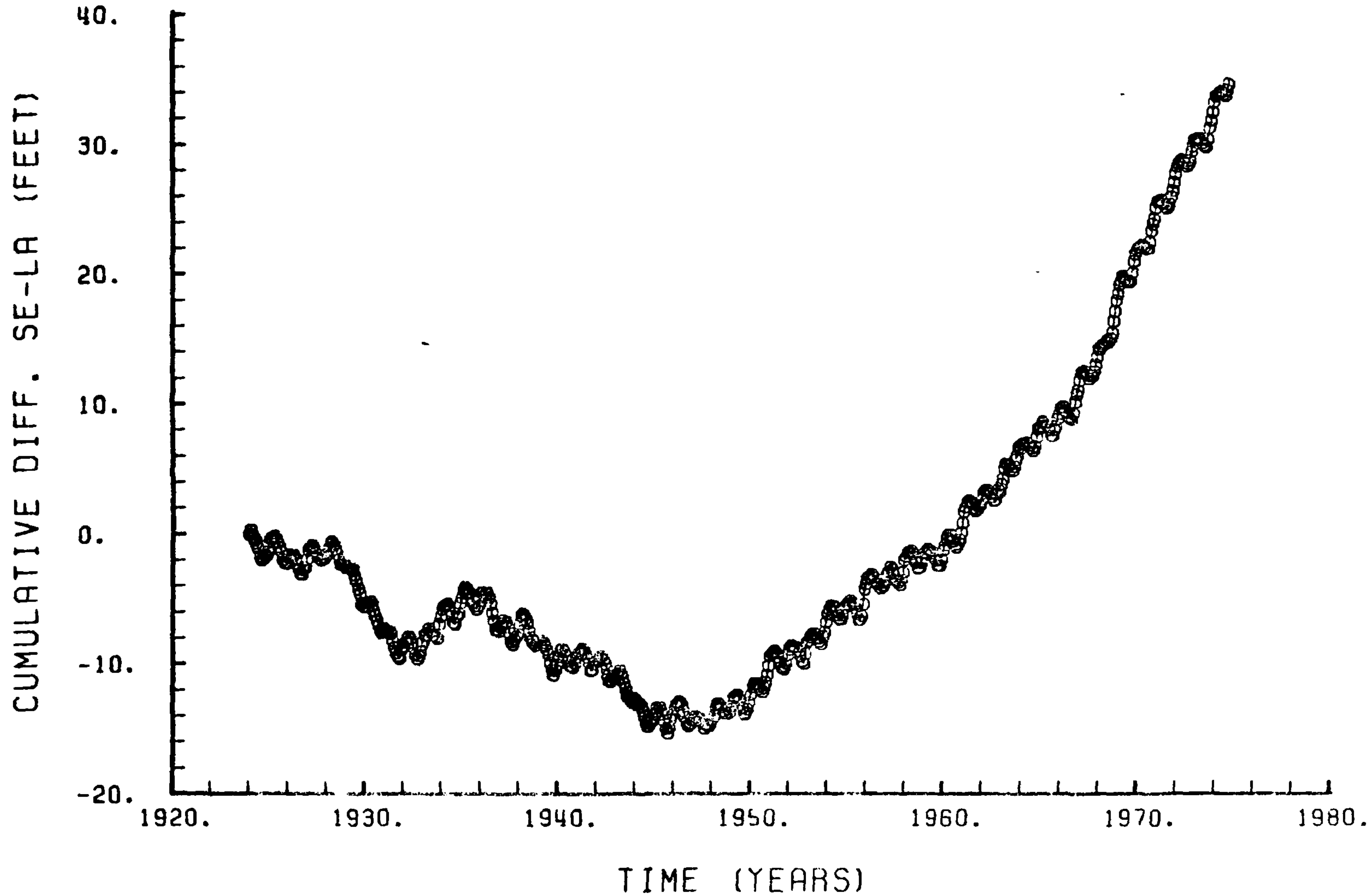

Figure 27. CUMULATIVE DIFFERENCES (SE-LA) USING RAW DATA AND MATCHING THE FIRST DATA POINTS

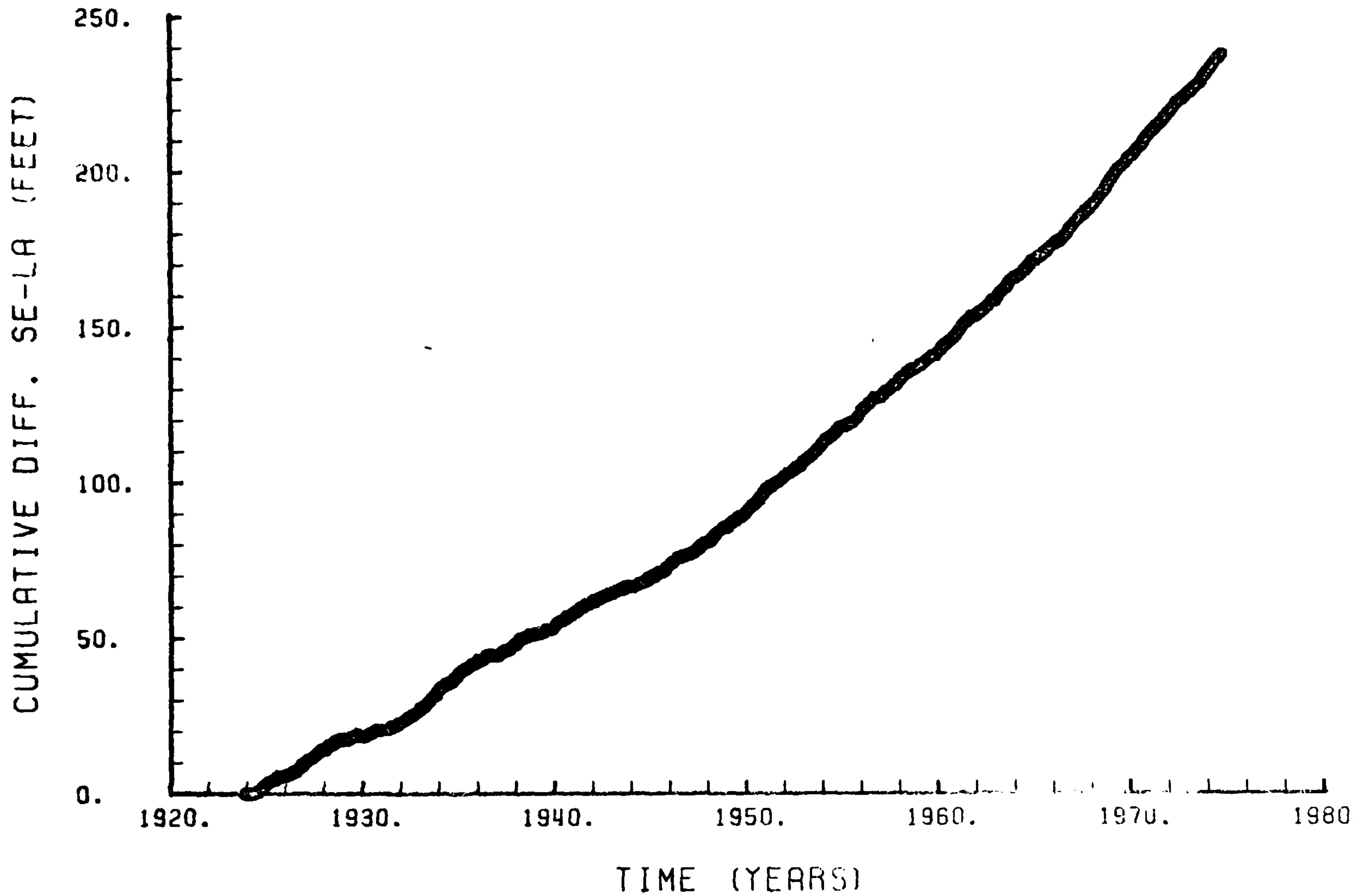

Figure 28. CUMULATIVE DIFFERENCES (SE-LA) USING ANOMALIES AND MATCHING THE FIRST DATA POINTS

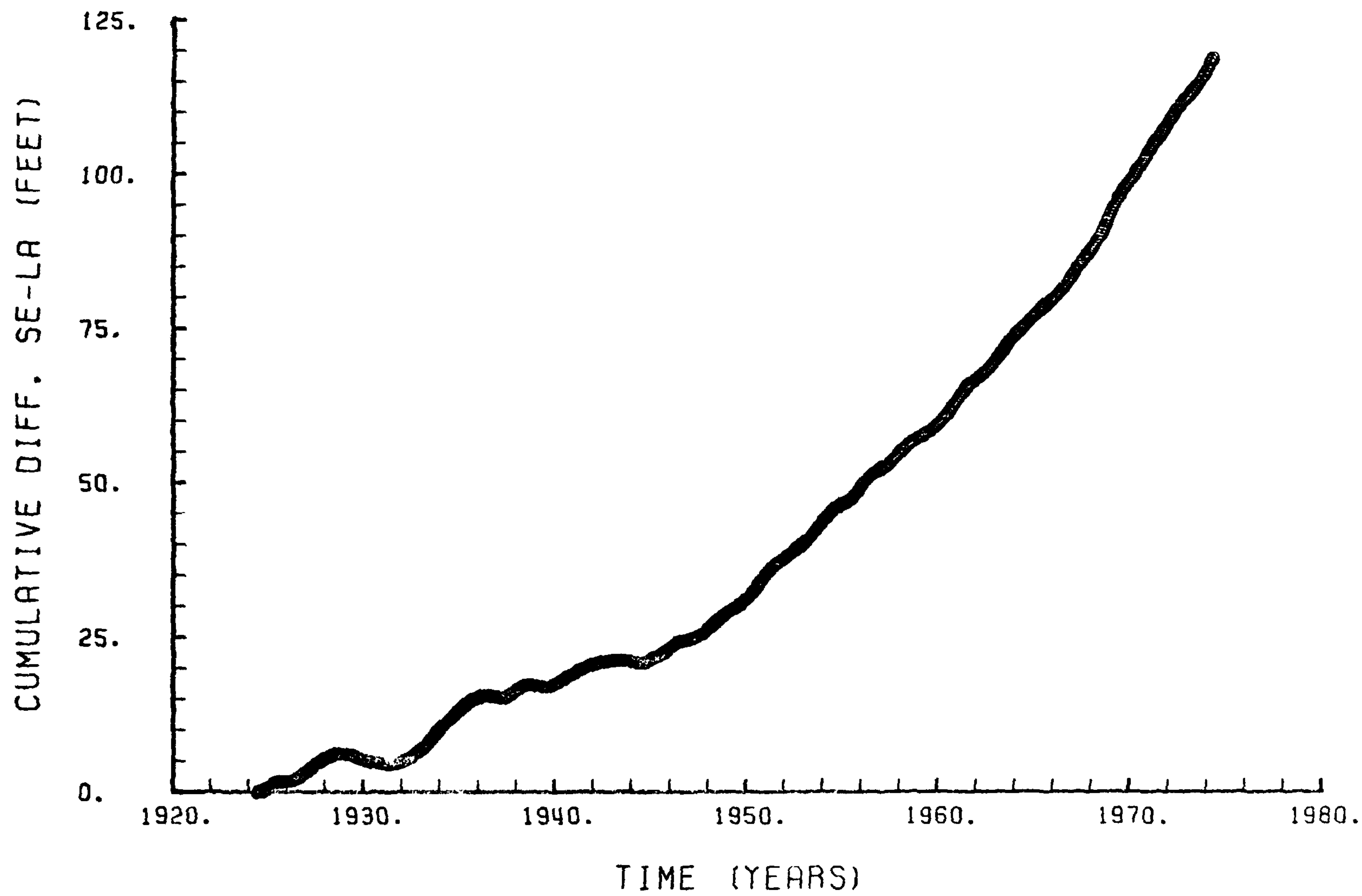

Figure 29. CUMULATIVE DIFFERENCES (SE-LA) USING 12 MO. R. M. AND MATCHING THE FIRST DATA POINTS

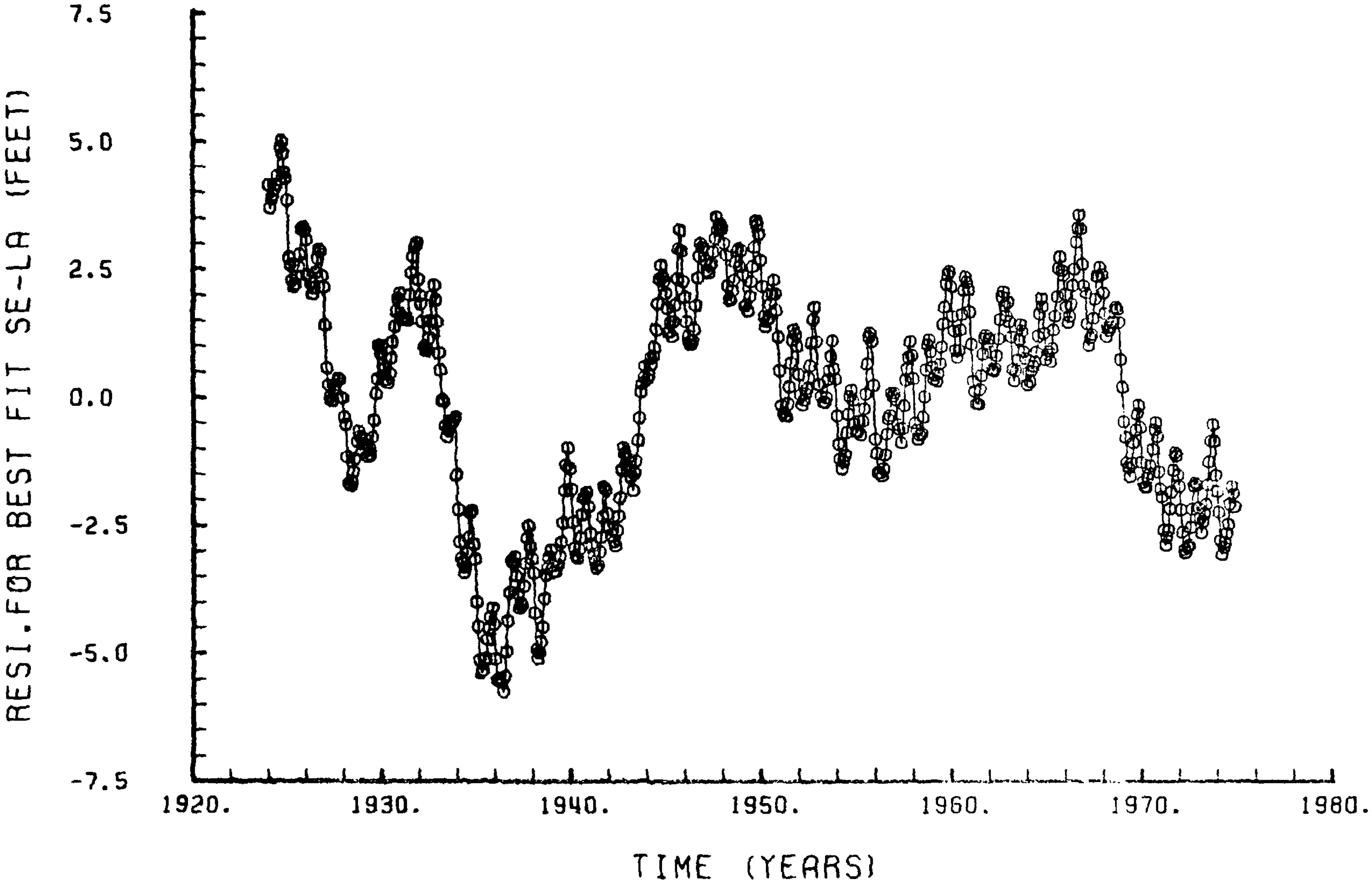

Figure 30. RESIDUALS FOR A SECOND DEGREE BEST FIT CURVE FOR SE-LA FOR 1924-1974 (USING RAW DATA)

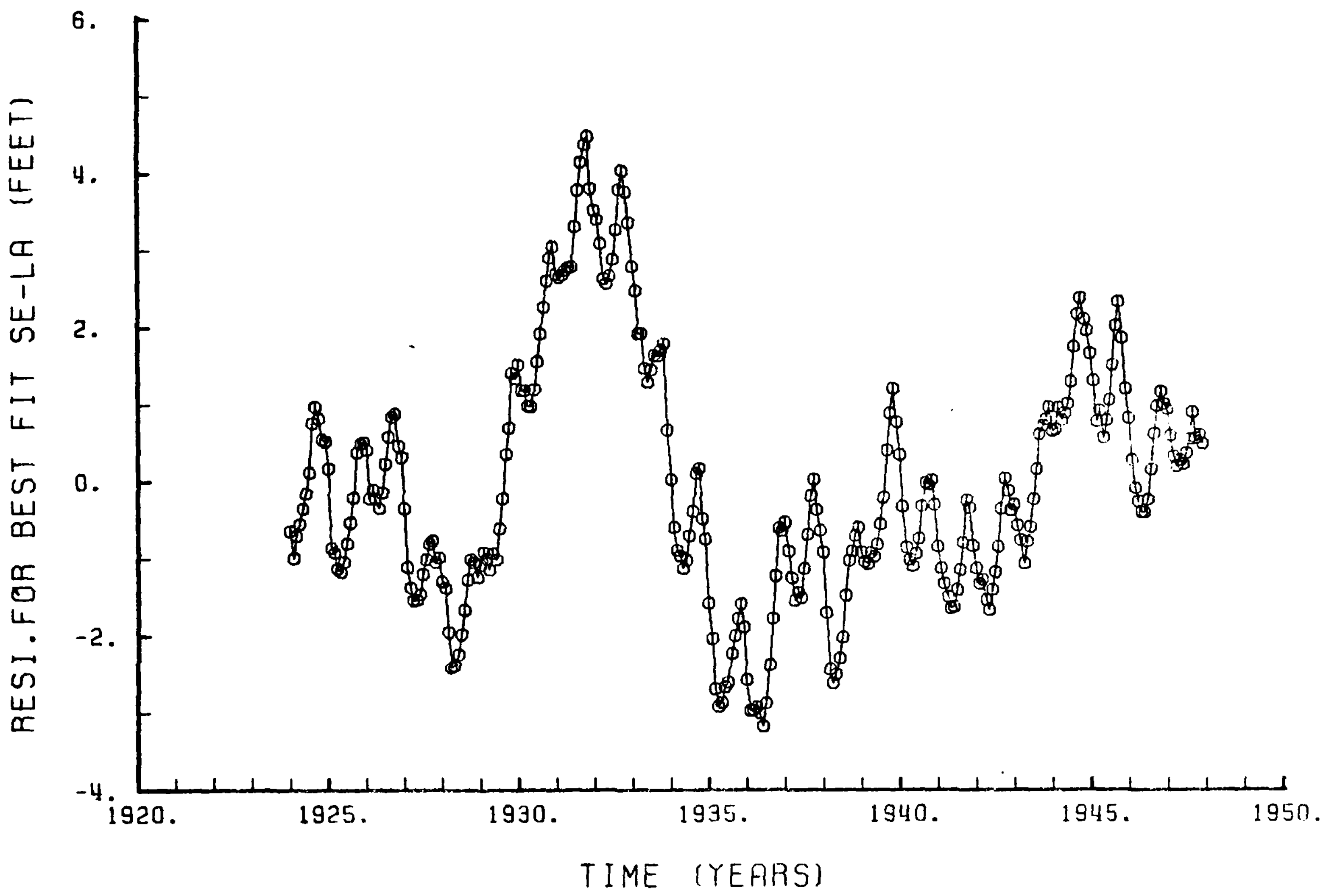

Figure 31. RESIDUALS FOR A FIRST DEGREE BEST FIT CURVE FOR SE-LA FOR 1924-1947 (USING RAW DATA)

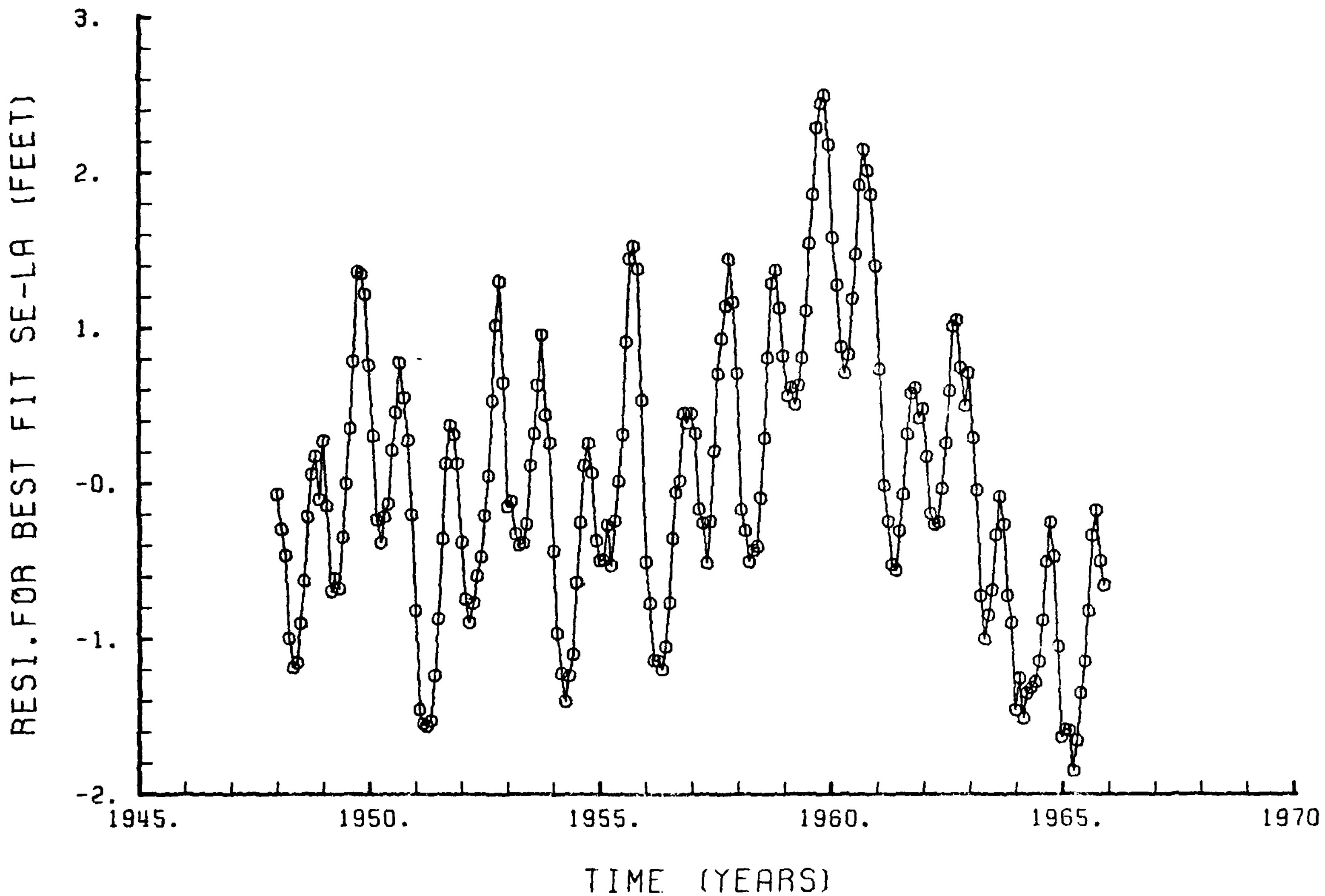

Figure 32. RESIDUALS FOR A FIRST DEGREE BEST FIT CURVE FOR SE-LA FOR 1948-1965 (USING RAW DATA)

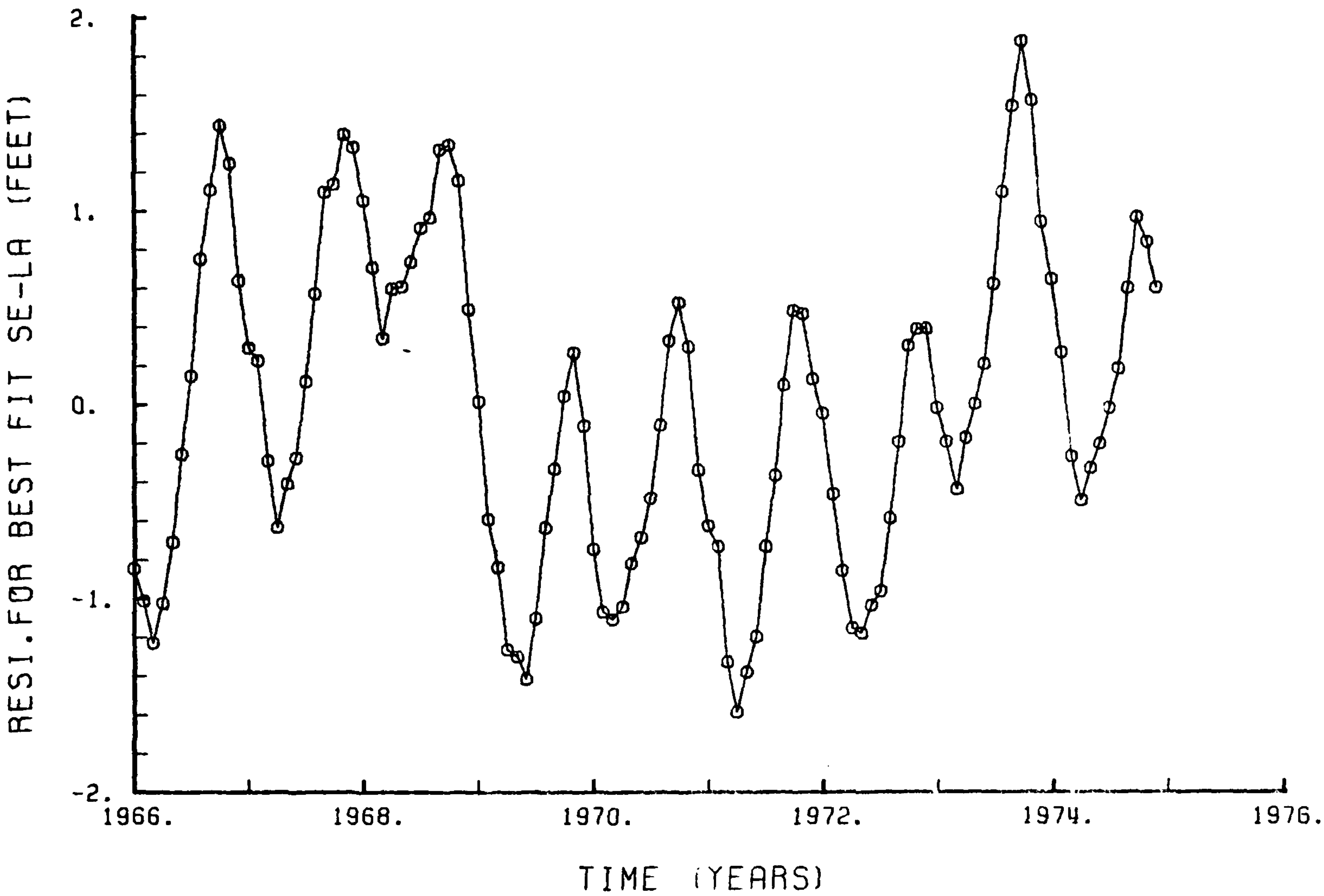

Figure 33. RESIDUALS FOR A FIRST DEGREE BEST FIT CURVE FOR SE-LA FOR 1966-1974 (USING RAW DATA)

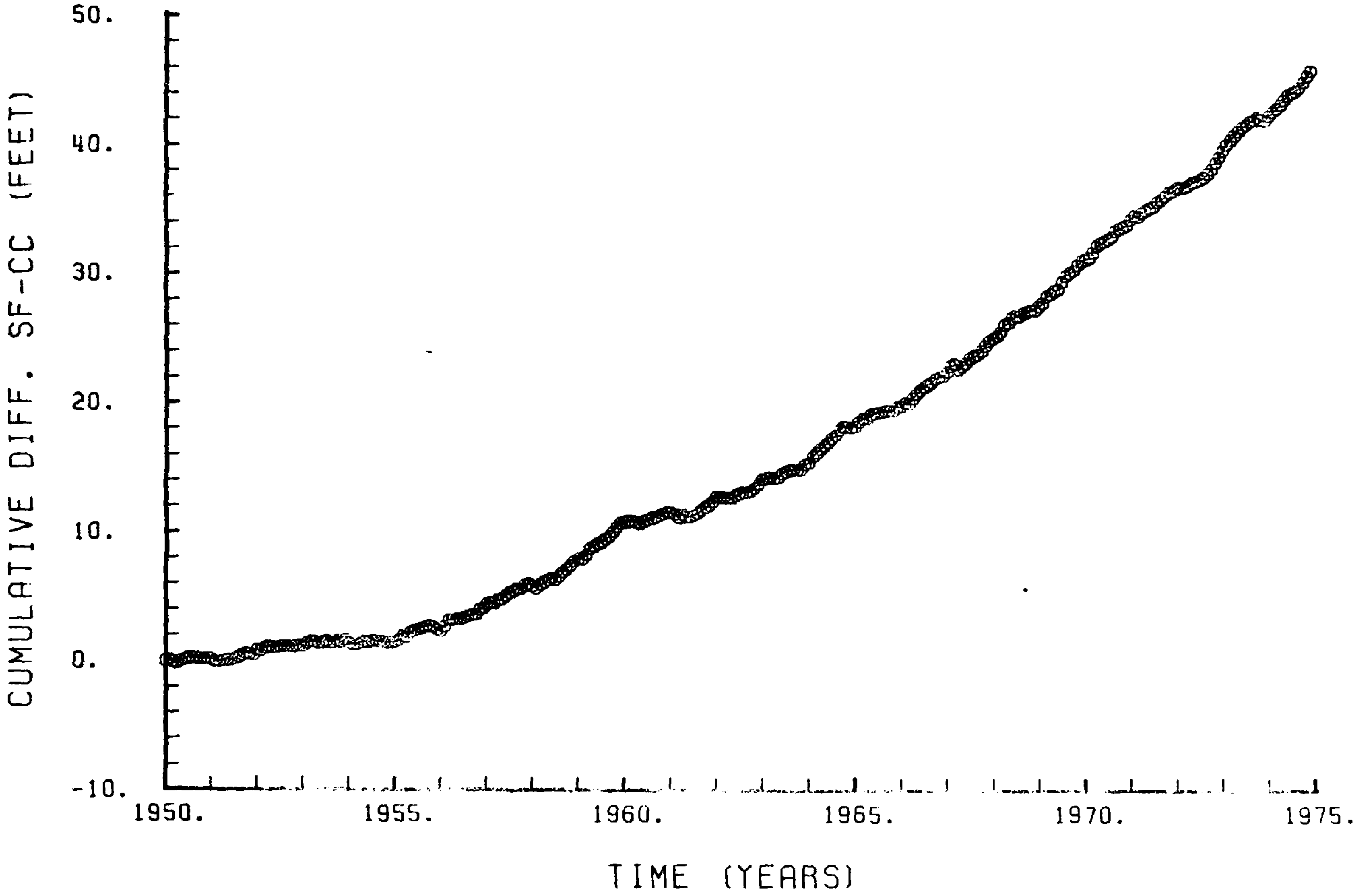

Figure 34. CUMULATIVE DIFFERENCES (SF-CC) USING ANOMALIES AND MATCHING THE FIRST DATA POINTS

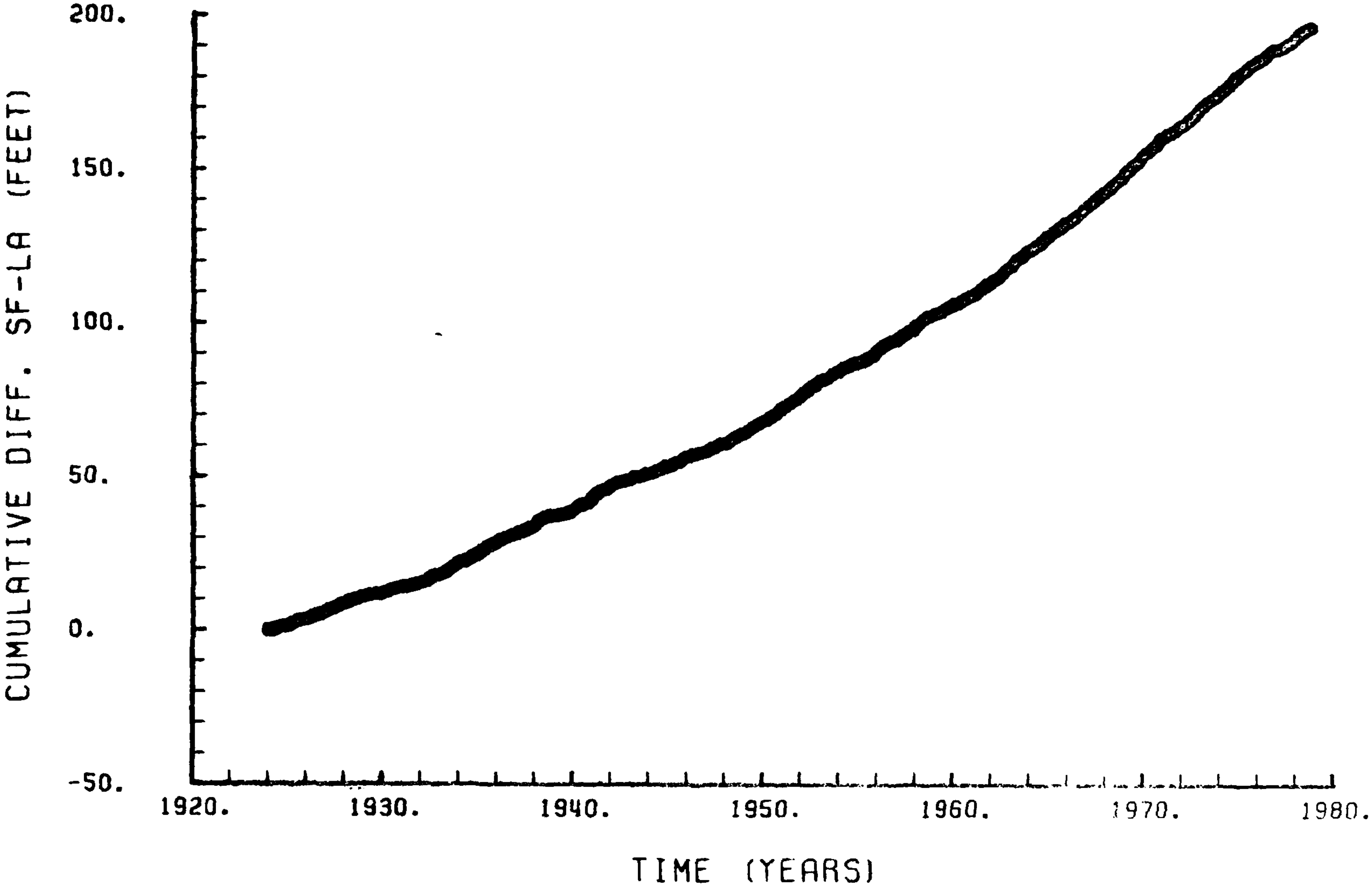

Figure 35. CUMULATIVE DIFFERENCES (SF-LA) USING ANOMALIES AND MATCHING THE FIRST DATA POINTS

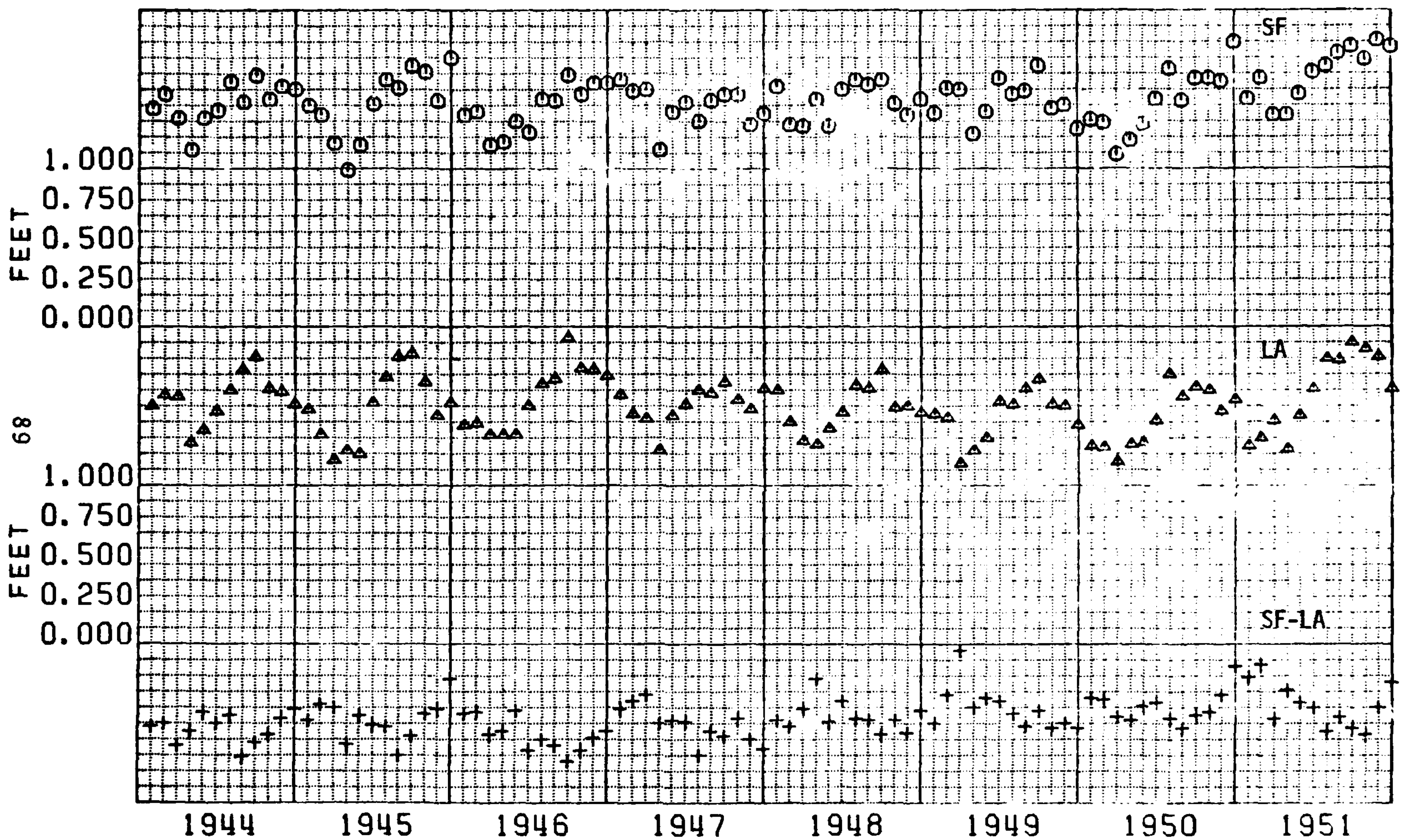

Figure 36. MEAN MONTHLY SEA LEVEL FOR SAN FRANCISCO (SF), LOS ANGELES (LA), AND SF-LA (1944-1951)

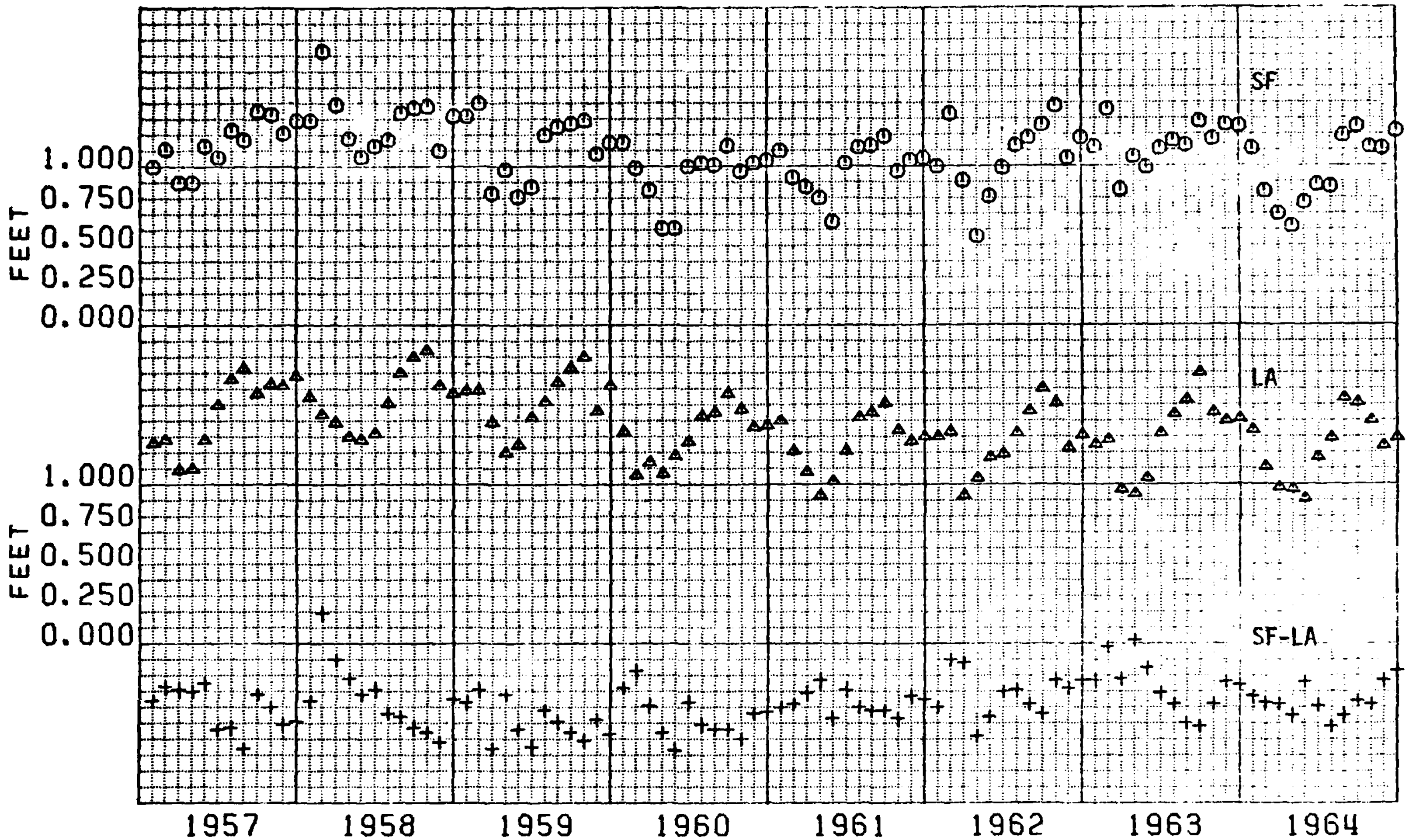

Figure 37. MEAN MONTHLY SEA LEVEL FOR SAN FRANCISCO (SF), LOS ANGELES (LA), AND SF-LA (1957-1964)

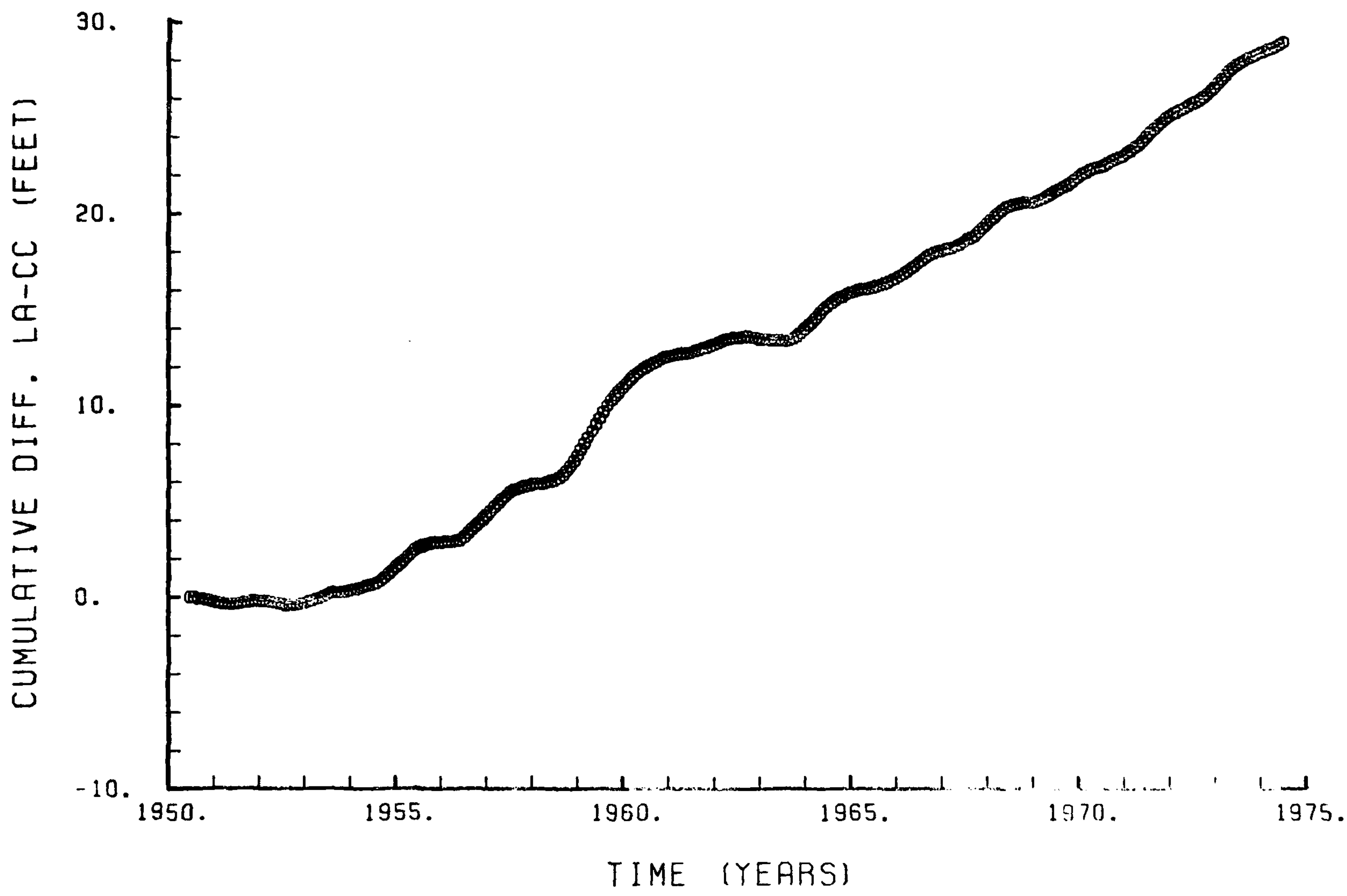

Figure 38. CUMULATIVE DIFFERENCES (LA-CC) USING 12 MO. R. M. AND MATCHING THE FIRST DATA POINTS

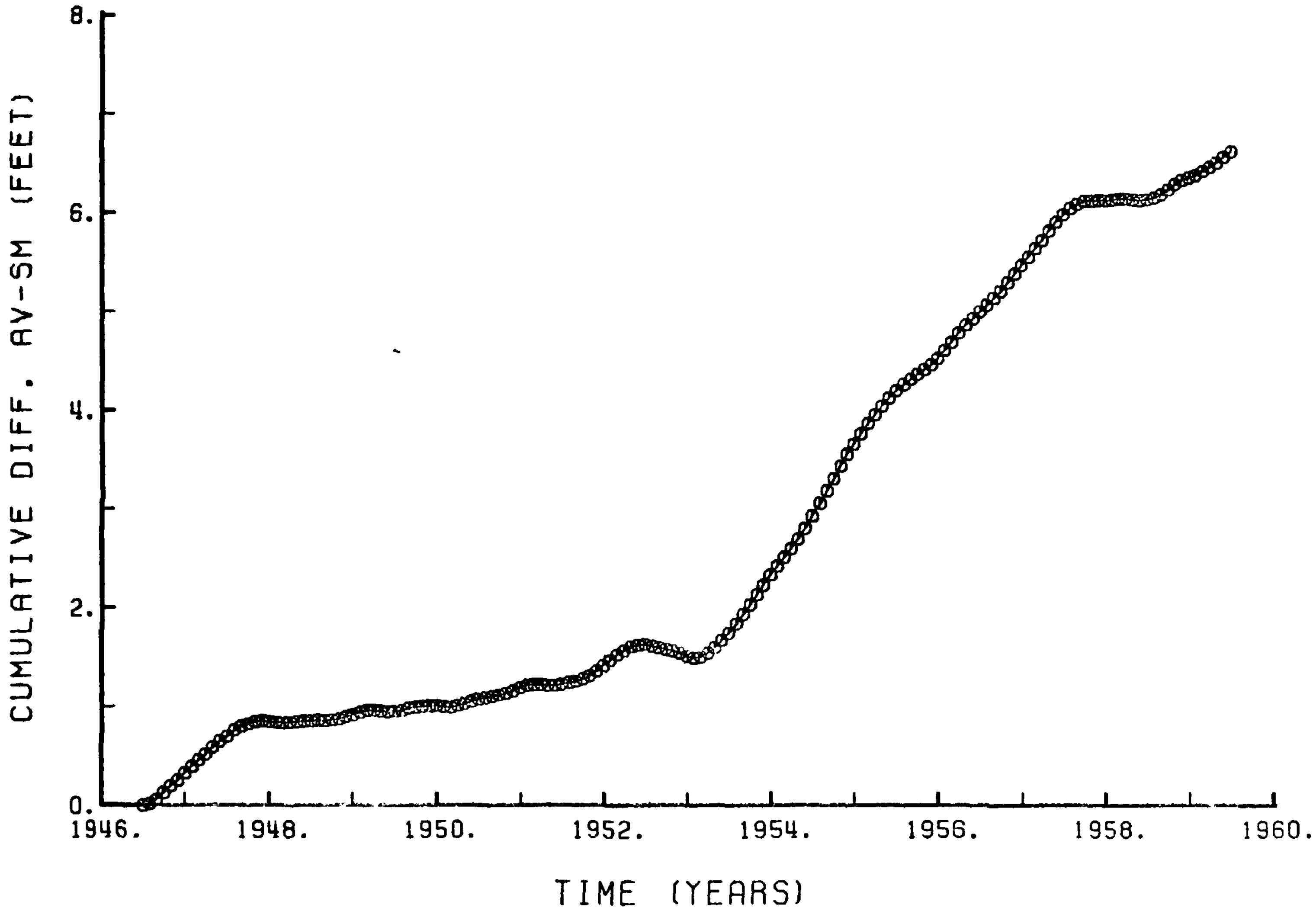

Figure 39. CUMULATIVE DIFFERENCES (AV-SM) USING 12 MO. R. M. AND MATCHING THE FIRST DATA POINTS

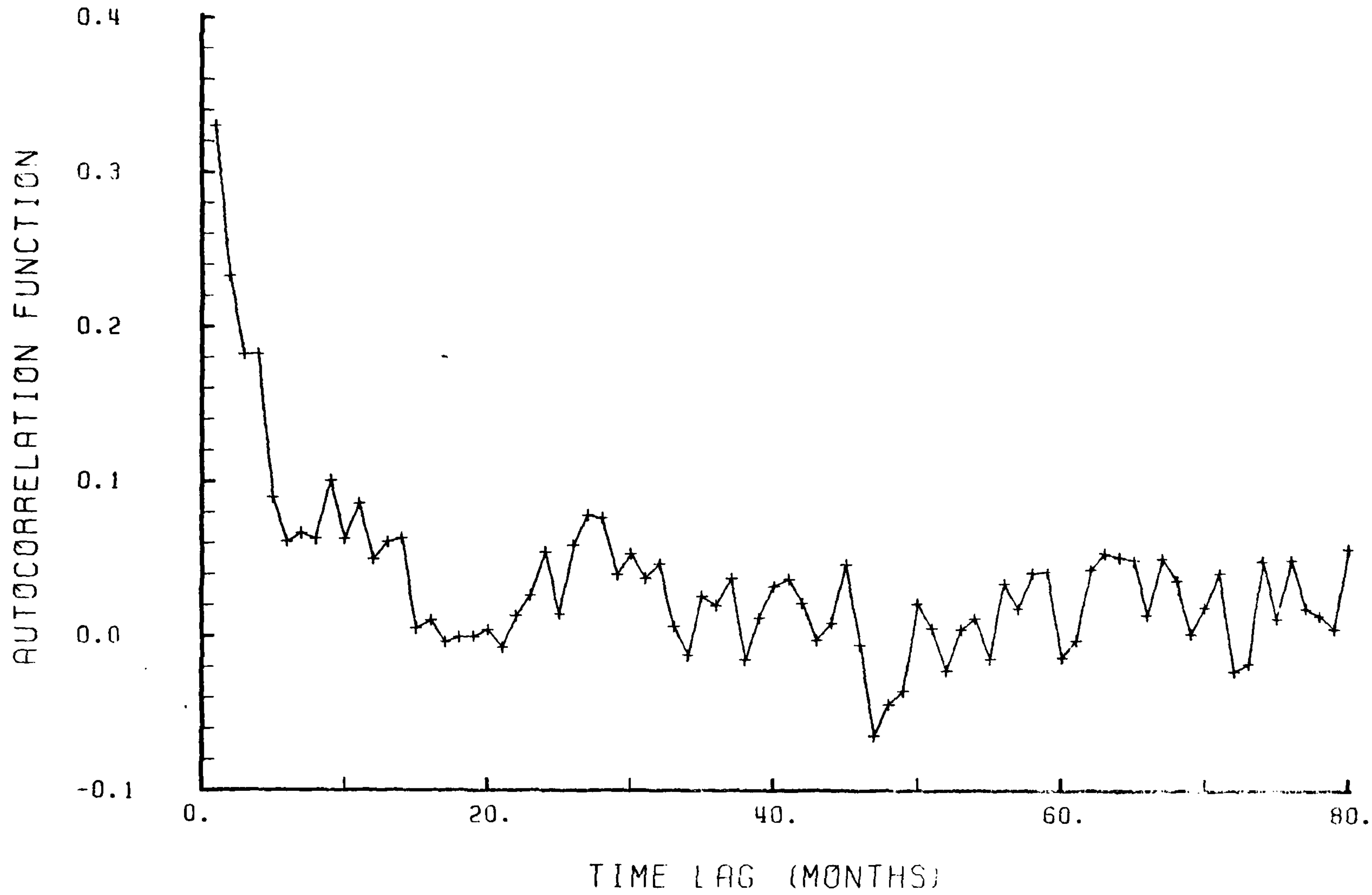

Figure 40. CORRELOGRAM FOR SEATTLE DATA (ANOMALIES)

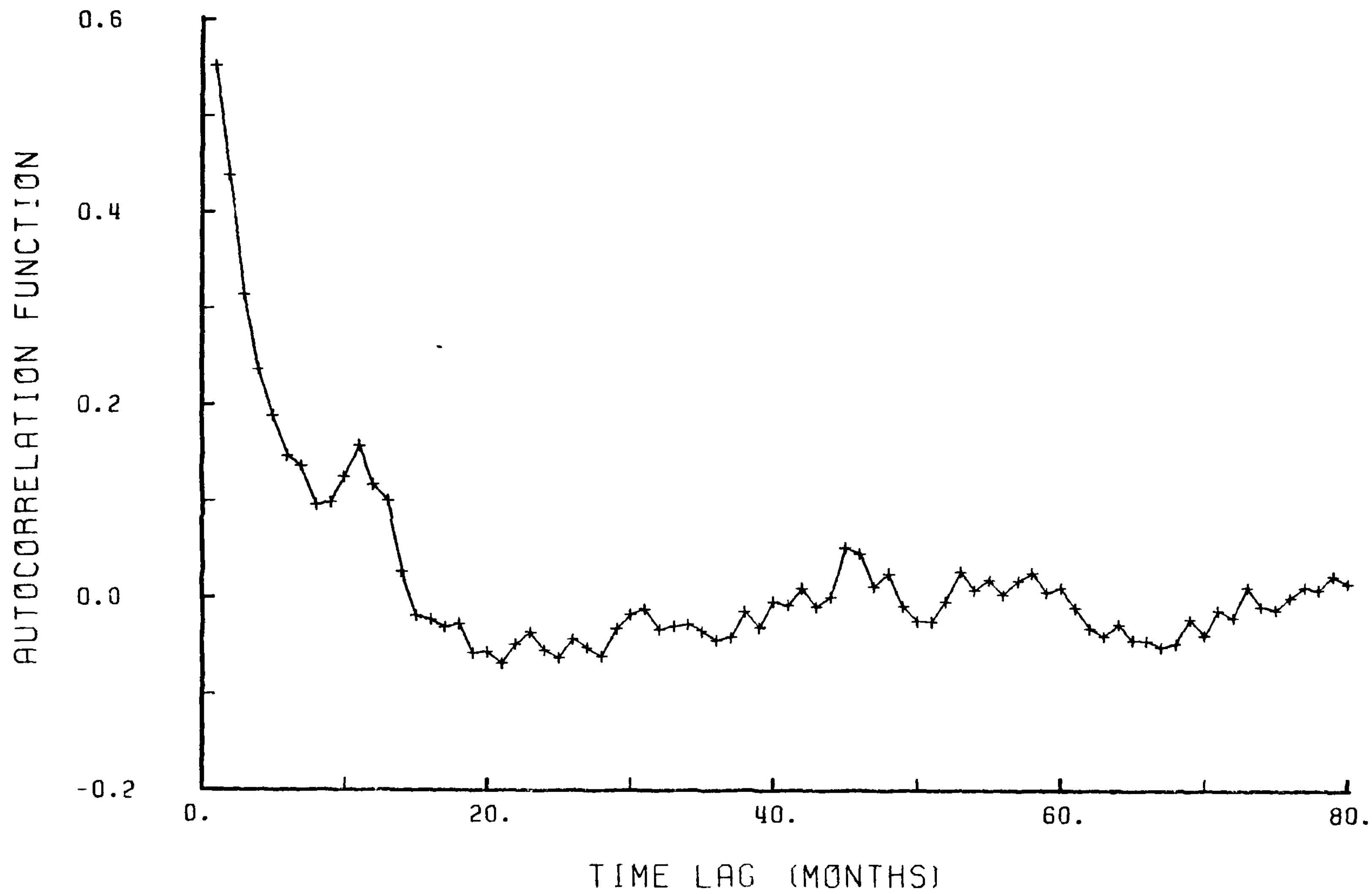

Figure 41. CORRELOGRAM FOR SAN FRANCISCO DATA (ANOMALIES)

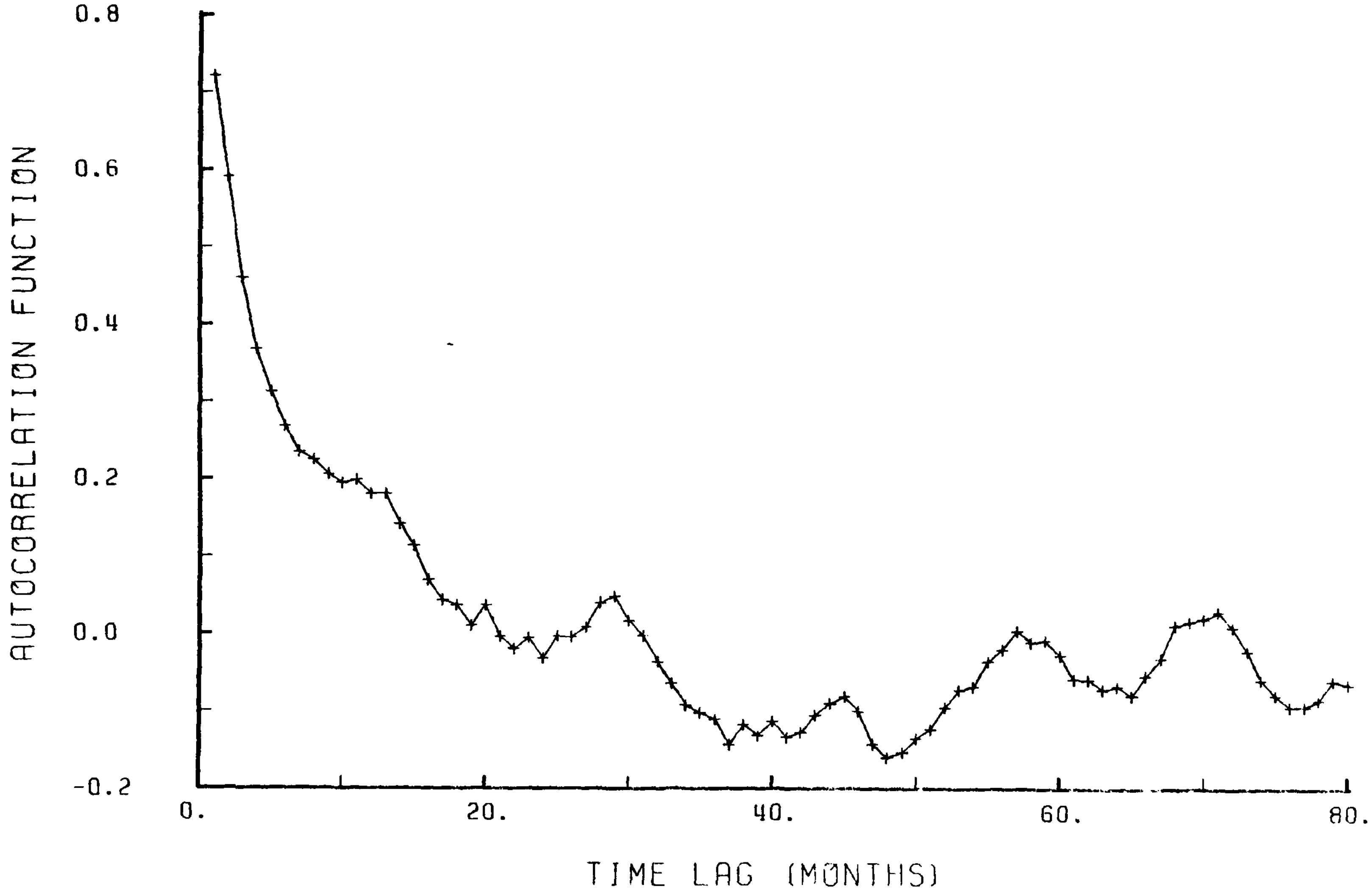

Figure 42. CORRELOGRAM FOR SANTA MONICA DATA (ANOMALIES)

AD-A094 573 NAVAL POSTGRADUATE SCHOOL MONTEREY CA F/G 8/5
DETERMINATION OF LAND ELEVATION CHANGES USING TIDAL DATA.(U)
SEP 80 F A ABREU
UNCLASSIFIED NL

2 OF 2
AD A094573

END
DATE FILMED
2-81
DTIC

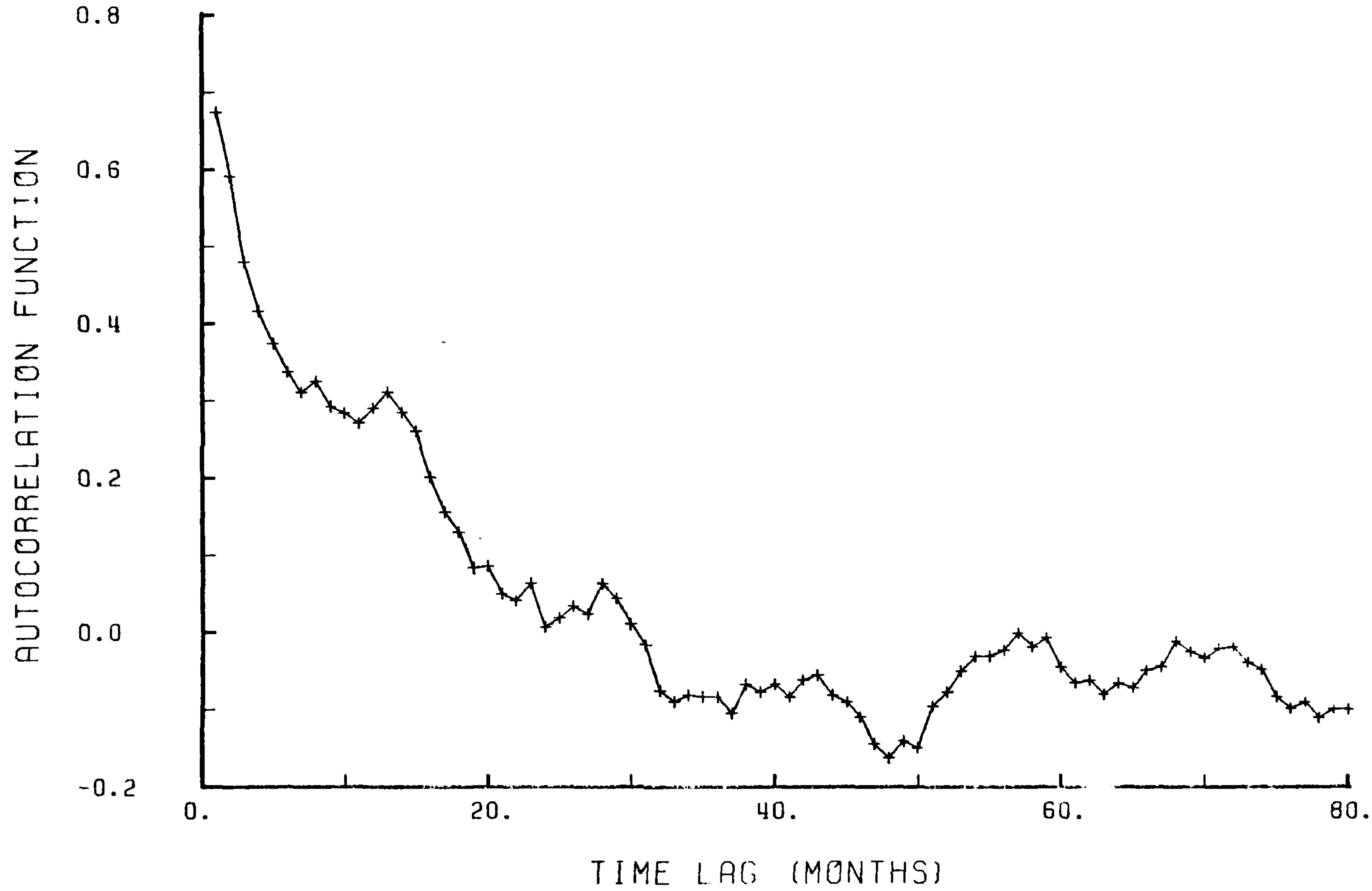

Figure 43. CORRELOGRAM FOR LOS ANGELES DATA (ANOMALIES)

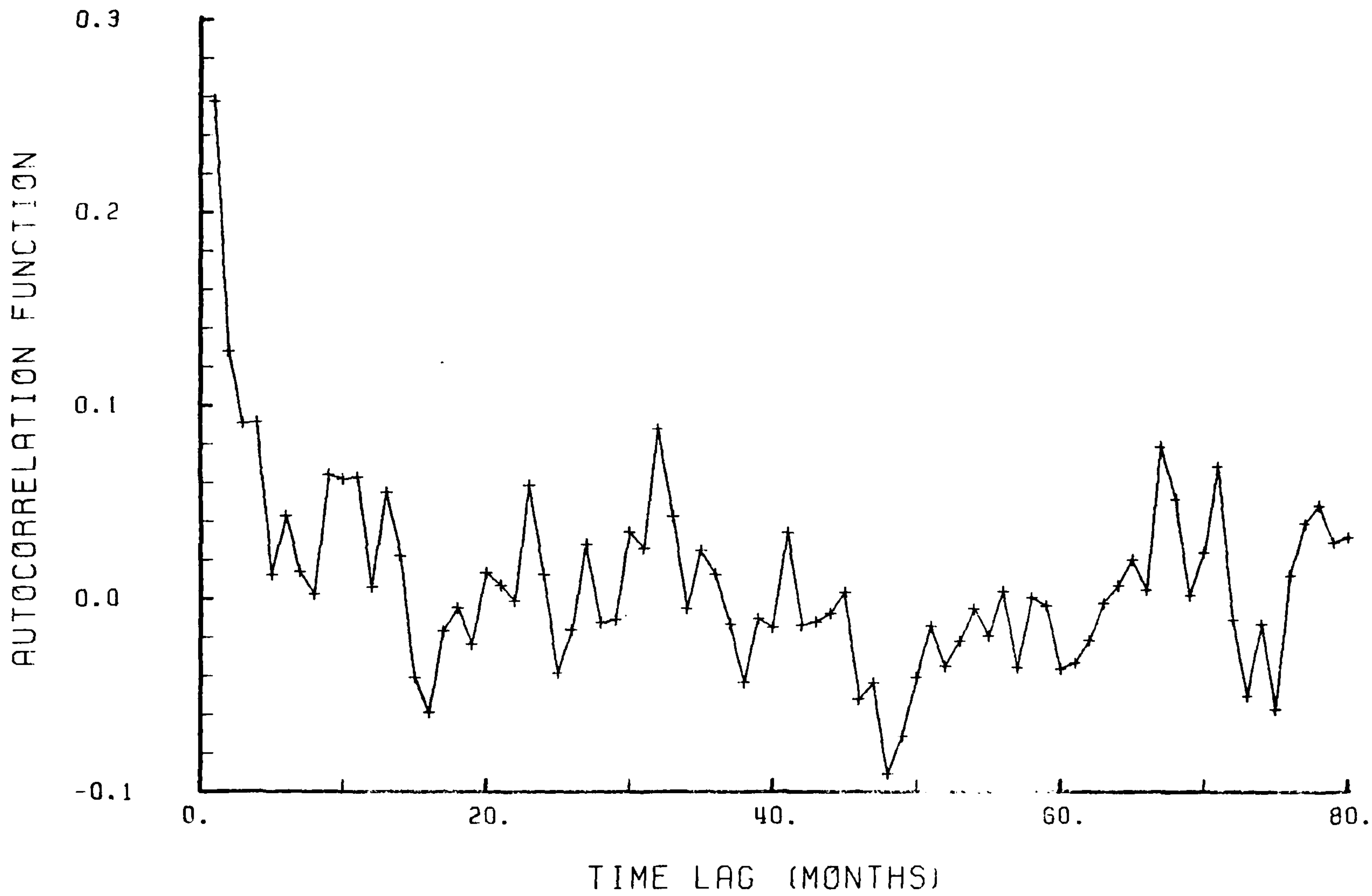

Figure 44. CORRELOGRAM FOR SE-SF (ANOMALIES)

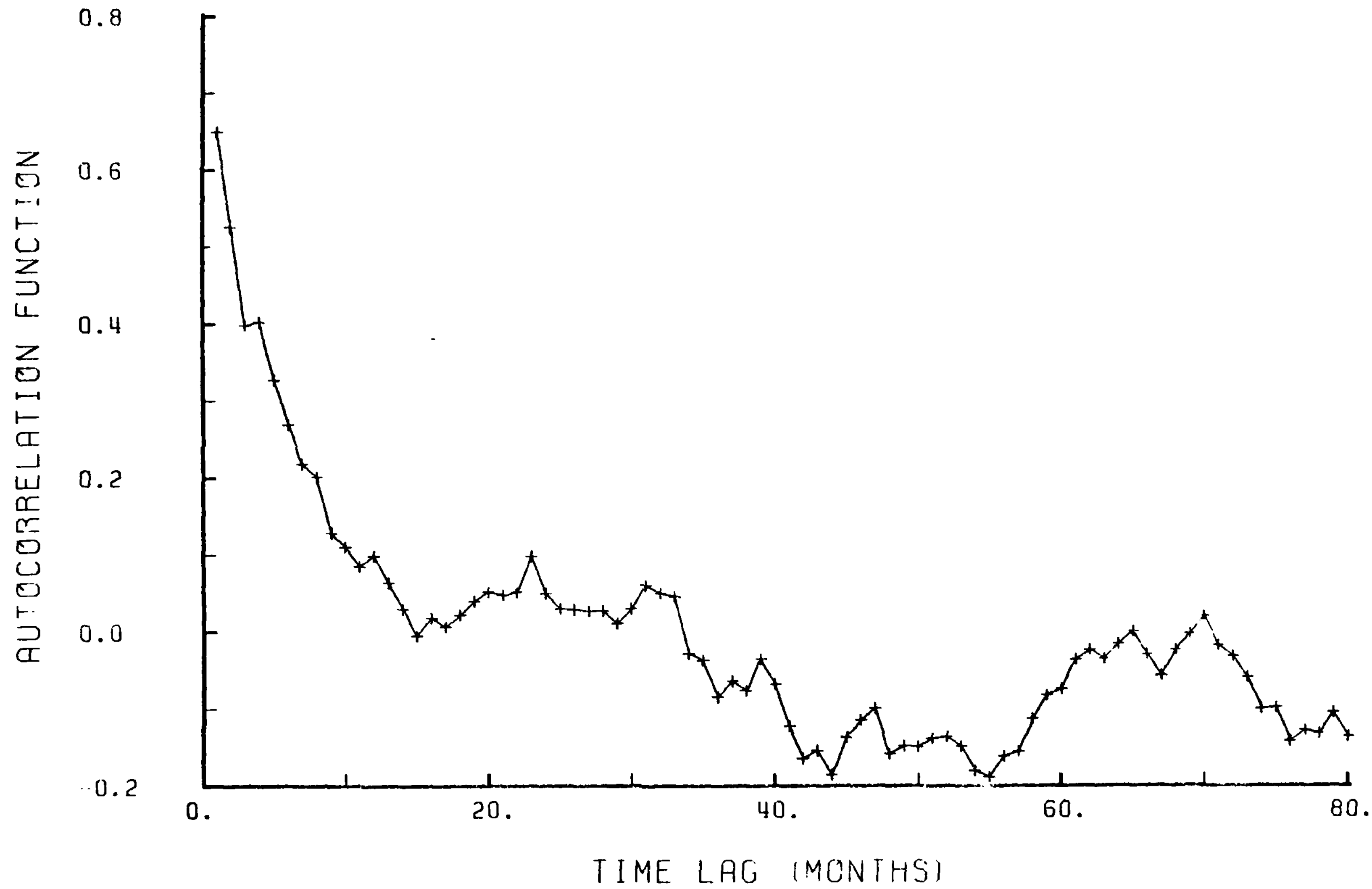

Figure 45. CORRELOGRAM FOR SM-LA (ANOMALIES)

APPENDIX A-1

PROGRAM USED TO PERFORM SPECTRAL ANALYSIS

```
      SUBROUTINE PREPFA(M,MS,DT,YYY,F1,PERIOD,FREQUE,NF)
C
C
C     MEANING OF THE PARAMETERS
C
C
C     M(INPUT) IS THE INTEGER POWER OF 2 ON THE EXPRESSION
C     2*2**M
C     MS(INPUT) IS THE NUMBER OF WINDOWS (ONE HALF OF THE
C     NUMBER OF DEGREES OF FREEDCM)
C     DT(INPUT) IS THE X-INTERVAL BETWEEN DATA PCINTS
C     YYY(INPUT) IS THE ARRAY TO BE ANALISED
C     F1(OUTPUT) IS THE ARRAY CONTAINING THE ENERGY VALUES
C     PERIOD AND FREQUE(OUTPUTS) ARE THE ARRAYS CONTAINING
C     THE VALUES OF THE PERIODS AND FREQUENCIES,RESPECTIVELY
C     NF(OUTPUT) IS THE NUMBER OF FREQUENCIES TO BE ANALISED
C     PLUS ONE
C
C
      DIMENSION YYY(1250),INV(1250),S(1250),F1S(1250),C(1250
     1),F1(1250)
      DIMENSION ART(1250),PERIOD(600),FREQUE(600)
  240 FORMAT('1',' POWER SPECTRUM IS CALCULATED',/' TOTAL NU
     *MBER OF SAMPLES=',T5,/1X,'THE TIME INCREMENT =',F5.3,/
     *1X,'THE NUMBER OF DEGREES CF FREEDOM FOR EACH SPECTRAL
     * ESTIMATE =',I5,///)
  250 FORMAT('0','STATISTICS OF SAMPLE NUMBER =',I4)
  260 FORMAT('C','MEAN VALUE =',F12.3,3X,'VARIANCE =',F12.3,
     *3X,'SKEWNESS =',F12.3,3X,'KURTOSIS =',F8.3,3X,'STD DEV
```

```
     *IATION =',F12.3)
 270 FORMAT('0',T10,F12.3,T25,F12.3,T40,F12.3)
     NM=2*2**M
     NM1=NM-1
     N=NM*MS
     NF=2**M+1
     NFREDM=MS*2
     T=NM*DT
     WRITE(6,240) N, DT, NFREDM
     DO 510 I=1,NF
510   F1(I)=0.
     IZ=0
     K=0
     DO 21 I27=1,N
      ART(I27)=YYY(I27)
  21 CONTINUE
     CALL AVERA(ART,N,AMEAN)
     DO 22 I28=1,N
      C(I28)=ART(I28)-AMEAN
  22 CONTINUE
     DO 520 MI=1,MS
     K=K+1
     DO 530 JJ=1,NM
     IZ=IZ+1
530   F1S(JJ)=C(IZ)
     WRITE (6,250) K
     CALL TREND(F1S,NM,DT,U11,U21,U31,U41,URMS1)
     CALL SPEC(F1S,M,INV,S,IFERR)
     WRITE (6,260) U11,U21,U31,U41,URMS1
     DO 540 I=1,NF
540   F1(I)=F1S(I)+F1(I)
520   CONTINUE
     DO 550 I=1,NF
     F1(I)=F1(I)*T/(2.*MS)
```

```
      IF(I.EQ.1)GC TO 23
      PERIOD(I)=FLOAT(NM)/FLOAT(I-1)
      FREQUE(I)=1.0/PERIOD(I)
      GO TO 24
   23 PERIOD(I)=FLOAT(NM)
      FREQUE(I)=0.0
   24 WRITE(6,270)F1(I),PERIOD(I),FREQUE(I)
  550 CONTINUE
      CALL PLOTG(FREQUE,F1,NF,1,1,1,'FREQUENCY IN CYCLES PER
     * MONTH',29,'
     1POWER DENSITY FUNCTION(FEET SQ.MONTH)',37,0.0,0.0,0.0,
     *0.0,7.5,5.0)
      CALL PLOT(0.0,0.0,+999)
      RETURN
      END
```

APPENDIX A-2

PROGRAM USED TO PERFORM LEAST SQUARES BEST FIT

```
      SUBROUTINE LEASTS(LLFIN,XX,YY,TREND,ERREST,ERRTRE)
C
C
C     MEANING CF THE PARAMETERS
C
C
C     LLFIN(INPUT) IS THE NUMBER OF DATA POINTS
C     XX AND YY(INPUT) ARE THE ARRAYS CONTAINING THE X AND Y
C     VALUES OF THE DATA(Y VALUES ASSUMED IN FEET)
C     TREND(OUTPUT) IS THE SLOPE OF THE REGRESSION LIN IN MM
C     PER YEAR
C     ERREST(OUTPUT) IS THE STANCARD ERROR OF THE ESTIMATE
C     IN MM
C     ERRTRE(OUTPUT) IS THE STANCARD ERROR OF THE TREND IN
C     MM PER YEAR
C
C
      CIMENSION XX(999),YY(999)
      DOUBLE PRECISION SUMMX,SUMMY,SUMMXX,SUMMYY,SUMMXY,TREN
     *C,ERREST,ERRTRE
  210 FORMAT('0')
  220 FORMAT(1X,3D24.15/)
      CONST1=3657.6
      CONST2=304.8
      SUMMX=0.0C0
      SUMMY=0.0D0
      SUMMXX=0.0D0
      SUMMYY=0.0D0
      SUMMXY=0.0D0
      DO 10 LS=1,LLFIN
```

```
      SUMMX=SUMMX+XX(LS)
      SUMMY=SUMMY+YY(LS)
      SUMMXX=SUMMXX+XX(LS)**2
      SUMMYY=SUMMYY+YY(LS)**2
      SUMMXY=SUMMXY+XX(LS)*YY(LS)
   10 CONTINUE
      TREND=(SUMMXY-SUMMX*SUMMY/FLOAT(LLFIN))/(SUMMXX-(SUMMX
     ***2)/FLOAT(LLFIN))
      ERREST=DSQRT((SUMMYY-SUMMY**2/FLOAT(LLFIN)-TREND*(SUMM
     *XY-SUMMX*SUMMY/FLOAT(LLFIN)))/FLOAT(LLFIN-2))
      ERRTRE=ERREST/DSQRT(SUMMXX-SUMMX**2/FLOAT(LLFIN))
      TREND=TREND*CONST1
      ERREST=ERREST*CONST2
      ERRTRE=ERRTRE*CONST1
      WRITE(6,220)TREND,ERREST,ERRTRE
      WRITE(6,210)
      RETURN
      END
```

APPENDIX A-3

PROGRAMS USED TO PERFORM FILTERING ACTION

```
      SUBROUTINE RMEAN1(NPER,LCOM,LFIM,DXREOT,DYREOT,NDIM,X,
     *Y,XB,YB,LCATA)
C
C
C     MEANING CF THE PARAMETERS
C
C
C     NPER(INPUT) IS THE NUMBER OF PERIODS CF CONTINUOUS DA-
C     TA(MORE THAN 12 POINTS) WITHOUT MISSING VALUES TO BE
C     ANALISED
C     LCCM AND LFIM(INPUT) ARE THE ARRAYS CONTAINING THE IN-
C     FORMATION CF THE BEGINING AND ENDING POINTS OF EACH
C     PERIOD
C     DXRECT AND DYREOT(INPUT) ARE THE ARRAYS CONTAINING THE
C     X AND Y VALUES TO BE FILTERED
C     NDIM(INPUT) IS THE DIMENSICN THAT SHOULD BE GIVEN TO
C     DXREOT AND DYREOT
C     X AND Y(INPUT) ARE DUMMY ARRAYS FOR SCALING PURPOSES
C     IF SOME PLOT IS INTENDED TO BE DONE WITH THE OUTPUT
C     ARRAYS
C     XB AND YB(CUTPUT)ARE THE ARRAYS CONTAINING THE X AND Y
C     VALUES ALREADY FILTERED
C     LDAT(OUTPUT) IS THE NUMBER OF DATA POINTS CONTAINED IN
C     THE CUTPLT ARRAYS
C
C
      DIMENSICN X(4),Y(4)
        DIMENSICN LCOM(20),LFIM(20)
      DIMENSION DXREOT(NDIM),DYREOT(NDIM),XA(1000),YA(1000)
```

```
      DIMENSION XB(1000),YB(1000)
      LCOUNT=1
      DO 62 L=1,NPER
       LBEG=LCOM(L)
       LSTOP=LFIM(L)
       LEND=LBEG+11
       SUM=0.0
       DO 60 L1=LBEG,LEND
        SUM=SUM+DYREOT(L1)
60     CONTINUE
       NDATA=LSTOP-LBEG-10
       DO 61 L2=1,NDATA
        YA(L2)=SUM/12.0
        XA(L2)=DXREOT(LBEG)+4.5+FLOAT(L2)
       YB(LCOUNT)=YA(L2)
       XB(LCOUNT)=XA(L2)
       LCOUNT=LCOUNT+1
        SUM=SUM-DYREOT(LBEG-1+L2)+DYREOT(LBEG+11+L2)
61     CONTINUE
62    CONTINUE
      LDATA=LCOUNT-1
      XB(LDATA+1)=X(3)
      XB(LDATA+2)=X(4)
      YB(LDATA+1)=Y(3)
      YB(LDATA+2)=Y(4)
      RETURN
      END
```

```
      SUBROUTINE ANOMAL(NY,NMO,YYY,WWW)
C
C
C     MEANING OF THE PARAMETERS
C
C
C     NY(INPUT) IS THE NUMBER OF YEARS OF DATA
C     NMO(INPUT) IS THE NUMBER OF MONTHS OF DATA
C     YYY(INPUT) IS THE ARRAY VALUES TO BE FILTERED
C     WWW(OUTPUT) S THE ARRAY VALUES AFTER BEING FILTERED
C
C
      DIMENSION YYY(1250),YY1(1250),WWW(1250)
      DIMENSION ARRTRA(12)
  210 FORMAT(1X,F12.3)
  220 FORMAT('0',3F12.3)
      DO 05 I=1,NMO
       YY1(I)=YYY(I)
   05 CONTINUE
      CALL TREND(YY1,NMO,1.0,U11,U21,U31,U41,URMS1)
      DO 20 I1=1,12
       ARRTRA(I1)=0.0
        J=I1
       DO 10 I2=1,NY
        ARRTRA(I1)=ARRTRA(I1)+YY1(J)
        J=J+12
   10  CONTINUE
       ARRTRA(I1)=ARRTRA(I1)/FLOAT(NY)
       WRITE(6,210)ARRTRA(I1)
   20 CONTINUE
      DO 30 I3=1,NMO
       MM=MOD(I3,12)
      IF(MM.EQ.0)MM=12
       WWW(I3)=YYY(I3)-ARRTRA(MM)
```

```
30 CONTINUE
   RETURN
   END
```

APPENDIX A-4

PROGRAM USED TO PERFORM CUMULATIVE ANALYSIS

```
      SUBROUTINE CUMMUL(NY,YEARIN)
C
C
C     MEANING OF THE PARAMETERS
C
C
C     NY(INPUT) IS THE NUMBER OF YEARS OF MEAN MONTHLY
C     VALUES TO BE ANALISE
C     YEARIN(INPUT) IS THE FIRST YEAR OF DATA
C
C
      DIMENSION X(4),Y(4)
      DIMENSION XNB(1000),XAS(1000)
      DIMENSION YNB(1000),YAS(1000)
      DIMENSION DYNBAS(1000),DXNBAS(1000)
      DIMENSION CUM(1000)
      DIMENSION WNB(1000),WAS(1000)
  201 FORMAT('0',3F10.2)
      NMO=NY*12
      CALL PAGE
      CALL REACCT(NY,X,Y,YNB,XNB,NP)
      CALL REACCT(NY,X,Y,YAS,XAS,NP)
      DO 05 I=1,NMO
      WNB(I)=YNB(I)
      WAS(I)=YAS(I)
   05 CONTINUE
      DO 30 III=1,3
      CALL AVERA(YNB,NP,AMEAN1)
      CALL AVERA(YAS,NP,AMEAN2)
```

```
      DIFF=AMEAN1-AMEAN2          OR        DIFF=YNB(1)-YAS(1)
      WRITE(6,201)AMEAN1,AMEAN2,DIFF
      CO 10 I=1,NMO
       YAS(I)=YAS(I)+DIFF
   10 CONTINUE
      CALL DIFFER(0,NMO,YNB,YAS,X,Y,DYNBAS,DXNBAS,NC)
      DELTAT=1./12.
      CUM(1)=DYNBAS(1)
      IF(III.EQ.3)YEARIN=YEARIN+0.5
      XAS(1)=YEARIN
      DO 20 I=2,NMO
       CUM(I)=DYNBAS(I)+CUM(I-1)
       XAS(I)=XAS(I-1)+DELTAT
   20 CONTINUE
      CALL PLOTG(XAS,CUM,NMO,1,1,1,'TIME (YEARS)',12,'CUMMUL
     1SM-SD (FEET)',30,0.0,0.0,0.0,0.0,7.5,5.0)
      IF(III.EC.2)GO TO 77
      IF(III.EQ.3)GO TO 30
      CALL ANOMAL(NY,NMG,YNB,YNB)
      CALL ANOMAL(NY,NMO,YAS,YAS)
      GO TO 30
   77 CALL RMEAN1(01,01,NMO,XNB,WNB,1000,X,Y,XNB,YNB,NP)
      CALL RMEAN1(01,01,NMO,XNB,WAS,1000,X,Y,XAS,YAS,NP)
      NMO=NP
   30 CONTINUE
      CALL PLOT(0.0,0.0,+999)
      RETURN
      END
```

APPENDIX A-5

CTHER SUBROUTINES CALLED

```
      SUBROUTINE AVERA (A,NPTS, AMEAN)
C
C
C     MEANING CF THE PARAMETERS
C
C
C     A(INPUT) IS THE ARRAY OF Y VALUES TO BE AVERAGED
C     NPTS(INPUT) IS THE NUMBER OF DATA POINTS OF A
C     AMEAN(OUTPUT) IS THE AVERAGE OF THE Y VALUES OF THE
C     INPUT ARRAY
C
C
      DIMENSICN A(NPTS)
      SUM=0.0
      DO 100 I=1,NPTS
      SUM=SUM+A(I)
100   CONTINUE
      AMEAN=SUM/FLOAT(NPTS)
      RETURN
      END
```

```
      SUBROUTINE TREND(FX,NTS,DT,FMEAN,U2,U3,U4,URMS)
C
C     SUBROUTINE TREND EDITS,CALIBRATES AND DETRENDS DATA
C
C
C     MEANING OF THE PARAMETERS
C
C
C     FX(INPUT) IS THE ARRAY OF Y VALUES.(OUTPUT) IS THE DE-
C     TRENDED ARRAY OF Y VALUES
C     NTS(INPUT) IS THE NUMBER OF DATA POINTS
C     DT(INPUT) IS THE X-INTERVAL BETWEEN DATA POINTS
C     FMEAN,U2,U3,U4,AND URMS(OUTPUTS) ARE THE MEAN,VARIANCE
C     SKEWNESS,KURTOSIS AND STANCARD DEVIATION OF THE INPUT
C
C
      DIMENSION FX(NTS)
C     EDITING CATA
C
C
      FNTS=NTS
C     COMPUTING THE LINEAR TREND
      SUMF=0.0
      DO 101 I=1,NTS
101   SUMF=SUMF+FX(I)
      SUMF1=0.0
      CO 102  I=1,NTS
      XI=I
102   SUMF1=SUMF1+XI*FX(I)
      XNM1=NTS-1
      XNP1=NTS+1
      XM=(1.0/CT)*(12.0*SUMF1/(FNTS*XNM1*XNP1)-6.0*SUMF/(XNM
     *1*FNTS))
      B=SUMF/FNTS-XM*XNP1*DT/2.0
```

```
      FMEAN=SUMF/FNTS
      WRITE (6,9) FMEAN,XM,B
9     FORMAT(3X,'MEAN=', F10.5,3X,'SLOPE =',F10.5,3X,'INTERC
     *EPT =',F10.5,//)
      DO  103 I=1,NTS
      XI=I
103   FX(I)=FX(I)-(B+XM*XI*DT)
C     SUBROUTINE FOR CALCULATING VARIANCE, STD DEV, SKEWNESS
C    *, KURTOSIS
      U2=0.0
      U3=0.0
      U4=0.0
      SUMU2=0.0
      SUMU3=0.0
      SUMU4=0.0
      DO 151 I=1,NTS
      U2=FX(I)*FX(I)
      U3=U2*FX(I)
      U4=U3*FX(I)
      SUMU2=SUMU2+U2
      SUMU3=SUMU3+U3
      SUMU4=SUMU4+U4
151   CONTINUE
      FNTS=NTS
      U2=SUMU2/FNTS
      URMS=SQRT(U2)
      U3=SUMU3/(FNTS*U2*URMS)
      U4=SUMU4/(FNTS*U2*U2)
      RETURN
      END
```

```
      SUBROUTINE  SPEC  (F1,M,INV,S,IFERR)
C
C     SUBROUTINE TO CALCULATE THE POWER SPECTRUM OF A SIGNAL
C    *USING RHARM
C
C
C     MEANING OF THE PARAMETERS
C
C
C     F1(INPUT) IS THE DETRENDED ARRAY OF Y VALUES.A MODIFI-
C     ED ARRAY APPEARS AT THE OUTPUT
C     M(INPUT) IS THE INTEGER POWER OF 2 OF THE EXPRESSION
C     2*2**M
C     INV(ARRAY),S(ARRAY),AND IFERR(OUTPUTS) ARE OUTPUTS OF
C     SUBROUTINE RHARM
C
C
      DIMENSION INV(515),S(515),F1(515)
      CALL RHARM(F1,M,INV,S,IFERR)
      NP=2**M-1
      NF=2**M+1
      NM=2*2**M
      NL=NM+1
      F1(1)=F1(1)*F1(1)
      DO 500 I=1,NP
      J=2*I+1
      L=I+1
      XR=F1(J)*F1(J)
      XI=F1(J+1)*F1(J+1)
      F1(L)=XR+XI
500   CONTINUE
      F1(NF)=F1(NL)**2
      RETURN
      END
```

```
      SUBROUTINE READOT(NUMYEA,X,Y,YNB,XNB,NP)
C
C
C     THIS SUBRCUTINE READS AND PRINTS THE DATA
C
C
C     MEANING CF THE PARAMETERS
C
C
C     NUMYEA(INPUT) IS THE NUMBER OF YEARS OF DATA TO READ
C     X AND Y(INPUT) ARE DUMMY ARRAYS FOR SCALING PURPOSES
C     IF SOME PLOT IS INTENDED TC BE DONE WIT& T&E CUTPUT
C     ARRAYS
C     YNB AND XNB(OUTPUT) ARE THE ARRAYS CONTAINING THE DATA
C     VALUES AND THE GENERATED ABSCISSAS,RESPECTIVELY
C     NP(OUTPUT) IS THE NUMBER OF DATA POINTS
C
C
      DIMENSION X(4),Y(4)
      CIMENSICN YNB(1250),XNB(1250),IYEAR(105)
  100 FORMAT(A4,7X,I4,12F5.2)
  200 FORMAT(1X,A8,2X,I4,12F5.2)
  210 FORMAT('0')
      ISTART=1
      IEND=12
      DO 10 I1=1,NUMYEA
       READ(5,100)NAME,IYEAR(I1),(YNB(INB),INB=ISTART,IEND)
      WRITE(6,200)NAME,IYEAR(I1),(YNB(INB),INB=ISTART,IEND)
      ISTART=ISTART+12
      IEND=IEND+12
   10 CONTINUE
      NP=IEND-12
      NUMMON=NUMYEA*12
```

```
      DO 20 I2=1,NUMMON
       XNB(I2)=FLOAT(I2)
   20 CONTINUE
      XNB(NP+1)=X(3)
      XNB(NP+2)=X(4)
      YNB(NP+1)=Y(3)
      YNB(NP+2)=Y(4)
      WRITE(6,210)
      RETURN
      END
```

```
      SUBRCUTINE CIFFER(IDELAY,ICOM,YNB,YAS,X,Y,DYNBAS,DXNBA
C
C
C     THIS SUBROUTINE PERFORMS DIFFERENCES BETWEEN TWO DATA
C     SETS,PRINTING THE RESULTS
C
C
C     MEANING OF THE PARAMETERS
C
C
C     IDELAY(INPUT) IS THE NUMBER OF MONTHS OF DELAY BETWEEN
C     THE FIRST AND SECOND TIME SERIES(POSITIVE IF THE SEC-
C     CND TIME SERIES BEGINS EARLIER THAN THE FIRST ONE)
C     ICOM(INPUT) IS THE NUMBER OF COMMON MONTHS TO BE
C     SUBTRACTEC
C     X AND Y(INPUT) ARE DUMMY ARRAYS FOR SCALING PURPOSES
C     IF SOME PLCT IS INTENDED TO BE DONE WITH THE OUTPUT
C     ARRAYS
C     YNB AND YAS(INPUT) ARE THE ARRAYS CONTAINING THE DATA
C     POINTS TC BE SUBTRACTED
C     DYNBAS AND DXNBAS(OUTPUT) ARE THE ARRAYS CONTAINING
C     THE RESULTS FROM THE DIFFERENCE COMPUTATION AND THE
C     COMMON ABSCISSAS,RESPECTIVELY
C     ND(OUTPUT) IS THE NUMBER OF DATA POINTS CONTAINED IN
C     THE CUTPUT ARRAYS DYNBAS AND DXNBAS
C      NCTE-THIS PROGRAM ASSUMES THAT THE MISSING VALUES OF
C           THE CATA ARE REPRESENTED BY 99.9 OR 00.0. IF
C           SOME MISSING VALUES CCCUR,ND WILL BE LESS THAN
C           ICCM
C
C
      CIMENSION YNB(1250),YAS(1250)
      DIMENSION DXNBAS(999),DYNBAS(999)
```

```
      DIMENSION X(4),Y(4)
  210 FORMAT('0')
  220 FORMAT(1X,2F6.2,I10)
      NN=1
      INIC=(IABS(IDELAY)-IDELAY)/2+1
      ABC=FLOAT(INIC)
      ISTOP=INIC-1+ICOM
      DO 20 JNBO=INIC,ISTOP
       JNBA=JNBO+IDELAY
       IF(YNB(JNBO).GT.90.0.OR.YNB(JNBO).LT.0.1)GO TO 2000
       IF(YAS(JNBA).GT.90.0.OR.YAS(JNBA).LT.0.1)GO TO 2000
       DYNBAS(NN)=YNB(JNBO)-YAS(JNBA)
       DXNBAS(NN)=ABC
       WRITE(6,220)DXNBAS(NN),DYNBAS(NN),NN
       NN=NN+1
 2000  ABC=ABC+1.0
   20 CONTINUE
      ND=NN-1
      DXNBAS(ND+1)=X(3)
      DXNBAS(ND+2)=X(4)
      DYNBAS(ND+1)=Y(3)
      DYNBAS(ND+2)=Y(4)
      WRITE(6,210)
      RETURN
      END
```

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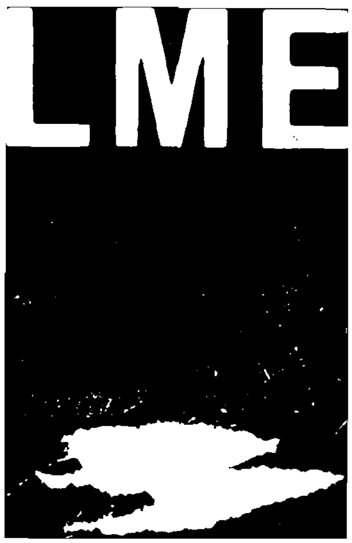
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